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Economic Geology

and the

Bulletin of the Society of Economic Geologists

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ECONOMIC GEOLOGY

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GENETIC RELATIONS OF GOLD DEPOSITS AND IGNEOUS ROCKS IN THE CANADIAN SHIELD.

E. S. MOORE.[1]

INTRODUCTION.

MOST geologists are still sufficiently conservative to believe in the genetic relations of ore deposits and igneous rocks that are closely associated in the field. The opinion of Holmes,[2] recently expressed so forcefully, that lead deposits originate independently of the magmas which supplied any of the associated igneous rocks has shaken the confidence of but few geologists in the value of such an association as a criterion in prospecting. The consensus is overwhelming that the Precambrian gold deposits may properly be tied to magmas of certain ages and to certain igneous rocks derived from them, which show many similarities in petrographic characters and, in a broad way, in magmatic sequences. In dealing with an area of over 1,800,000 square miles, the remarkable similarity in many of the features, both major and minor, in the areas where gold occurs, is very impressive. Such a situation is partly the result of long periods of erosion reducing the shield to a level where the granitic rocks, which almost everywhere seem to underlie the continental masses at great depths, prevail, and conditions have progressed far toward uniformity. The hypothermal portions of the vein systems alone remain and in many respects the gold deposits throughout the shield appear to be more

[1] Presidential address delivered before the Society of Economic Geologists at a joint session of the Society and the Geological Society of America, Minneapolis Meeting, December 29, 1939.

[2] Holmes, A.: The origin of primary lead ores. ECON. GEOL., 32: 763–782, 1937 and 33: 829–867, 1938.

uniform in many of their characters than those formed outside the shields where a greater diversity of geological conditions exist.

MAJOR DIVISIONS OF THE PRECAMBRIAN.

The difficulties encountered by the Precambrian geologist in dealing with chronology are too familiar to require enumeration. He is often dependent for chronological data on igneous sequences, and widespread batholithic injections of granite with assumed concomitant mountain-building, which would lead to erosion and deposition now represented by mere remnants of sediments.

It is not my intention to enter here on a detailed discussion of correlation problems of the Precambrian, because this would lead into many blind alleys and raise questions bristling with controversy. I would like to have it distinctly understood that in making the following statements it is not considered that the ages of all the granites and gold deposits mentioned have been settled beyond all doubt. Some more accurate means of determining the ages of Precambrian rocks than we now possess is necessary before we can feel sure of them, and the conclusions drawn in this paper are only the results of the acceptance of opinions regarding ages expressed by a large number of men who have worked in the areas concerned. It must be recognized that there are fashions in geology, as in other matters, and at this stage in our geological studies it may be fashionable to assign gold deposits to the Algoman system, just as it was at an earlier period fashionable to call practically all of the Precambrian granites Laurentian. An abbreviated classification that presents the divisions most concerned in this discussion is as follows:

Keweenawan:	Sediments; volcanics; diabase and gabbro on a large scale; granite batholiths, and minor gold deposits.
Animikie:	Sediments and minor volcanics.
Huronian:	Cobalt sediments. Bruce sediments.
Matachewan:	Diabase and gabbro.
Algoman:	Igneous rocks dominantly acid but with large quantities of intermediate and relatively small quantities of basic rocks. Granite batholiths and gold deposits of major importance.
Haileyburian and other post-Timiskaming:	Dominantly basic and ultra-basic rocks, with some diorite.

Timiskaming: Dominantly sedimentary with volcanics in some areas. Sediments of wide derivation.
Laurentian: Almost entirely granitic rocks in batholitic injections, with minor gold deposits.
Keewatin: Chiefly volcanic rocks with minor quantities of sediments mostly of local derivation.

In this classification certain recognized series have been omitted to avoid difficulties in correlating them, but it shows an important feature that is generally recognized, and that is the existence of three systems with granite batholiths and gold deposits. Of these, the Laurentian and Algoman granites had a much wider distribution than those of the Keweenawan, although the Laurentian granite is not now found in place in many areas. Its distribution is attested by the widespread occurrence of boulders of this rock in the Timiskaming conglomerate. The latter rock is intruded by the Algoman granites and questions that naturally arise are: what became of the great masses of earlier granite, and does the Algoman represent the remelted Laurentian, or how otherwise could it have been displaced? If such remelting occurred, did it play any part in furnishing the more abundant gold to the Algoman magmas?

PERIODS OF GOLD DEPOSITION.

In perusing a large number of geological reports dealing with areas and gold camps in the Canadian shield, seventy-five have been considered in which the rock formations were chronologically arranged in accordance with the classification given above. In others the data were insufficient to make assignments of the rocks and gold deposits on a basis of relative age. Every gold deposit mentioned in the seventy-five reports was regarded as belonging to one of the three systems; Laurentian, Algoman and Keweenawan, with their granite batholiths.

The close genetic and structural relationships of gold deposits and batholiths, have been so clearly demonstrated by W. H. Emmons in his many papers on this subject, not only in the Canadian shield but in other shields as well, that they are generally accepted without hesitation by those who have studied the subject in the field. There are, however, many problems con-

cerned with the occurrence of the gold that have not been settled. For example, it is estimated that over 95 per cent of all the gold so far found in the Canadian shield has come from the Algoman. In this estimate, Noranda, in Quebec, has not been included because there is still a decided difference of opinion among geologists who have studied the ore deposits as to whether most of the gold is younger or older than a diabase dike that cuts some of the ore. This dike is probably Keweenawan and if the ore is younger than the dike it might be Keweenawan and the estimate mentioned would be changed materially.

Why this dominance of gold in the Algoman? Is it due to wider distribution of rocks of this age; more extensive and elaborate differentiation in magmas producing greater concentration of the metal; or better structural control?

As stated, the distribution of Algoman granites in place is much greater than that of the Laurentian or Keweenawan, and the number of gold deposits that have attracted some attention is greater per given area for the Algoman than for the Laurentian. In the case of the Keweenawan the difference in number for equal areas is, however, about the same, and the main factor is the much greater size of a considerable number of the Algoman deposits. The situation is well illustrated in southeastern Ontario where a large number of gold deposits are grouped around an area of granite regarded as Algoman, whereas relatively few occur with the older granites.

In the extent of differentiation, with the production of a diversity of igneous rocks, the Algoman, as will be shown when magmatic sequences are discussed, far surpasses the other two systems, which reveal comparatively little diversity in rock species. And yet, the number of gold deposits which occur with the Killarney granite of the Keweenawan system, in a relatively small area, leads one to the conclusion that a great diversity of differentiation products does not appear to be the only factor in the production of gold. There must be something else that exerts a controlling influence and that is apparently structure. The question might be asked as to why the Laurentian granites were not intruded under as favorable structural conditions as the Algoman.

The difference is probably due to the fact that when the latter rocks were injected there were many more favorable structures in existence than when the first great batholithic intrusions with accompanying mountain-building occurred. Both old and new structures were available for the formation of deposits. Then again the Keweenawan granites were injected mostly into the Huronian sediments some of which are shaly in nature and not very favorable ground.

MAGMATIC SEQUENCES.

Since an early date, petrographers have generally recognized that as differentiation of magmas progresses, the products tend to become, on the whole, more and more acid in character. The progress toward more acid products does not always proceed uniformly but in certain cases by steps, and in places the process seems to show a descent from the basic to the acid along two converging lines that are followed by the more femic and more salic constituents. This situation appears to produce reversals in the order of formation of the salic and femic rocks and alternations in order of intrusion result. This tendency to alternate is probably best explained by applying the *reaction principle* so ably expounded by Bowen.[3] In the cases where plutonic rocks are concerned, the greatest diversity in the character of the rocks is found in the satellitic bodies that tend to develop toward the closing stages in the crystallization of the magma. It is here that are found the complementary dikes and diaschistic dikes, and such rocks as lamprophyres, aplites, alaskites, pegmatites, albitites and quartz veins.

It is of interest to examine individually the three systems discussed above to see whether they conform to the accepted plan of differentiation in plutonic bodies.

Laurentian.—In few areas is there any definite evidence of plutonic basic rocks preceding the great injections of granite. The immense extrusions of basic to intermediate lavas of the Keewatin might possibly be regarded as a phase of the granite magmas and

[3] Bowen, N. L.: The Evolution of the Igneous Rocks. Princeton Univ. Press, 1928.

there are also coarse-grained basic intrusives in the Keewatin, but these can not be definitely tied to those magmas. The numerous occurrences of acid lavas and dikes of porphyry that are found in the Keewatin in some areas might also be considered as the shallow manifestations of the same magmas. As for diverse end products of a sequence, there are scarcely any except pegmatites and quartz veins, the latter of which are mostly barren of metals. In a great many areas only granite is mapped as Laurentian, in others quartz porphyry and granite, and in some syenite is mentioned with the granite.

Keweenawan.—In dealing with this system, because of lack of time, discussion of the more complex situation in the Lake Superior basin, where sediments and volcanics, and intrusives of several types occur together, will be omitted. Attention will be confined chiefly to the remarkable series of intrusions of diabases and granite. The former extend over a large section of the shield and the latter, so far as known, is confined mainly to the Lake Huron and Lake Superior regions where the orogeny that developed the Lacloche mountains occurred. The sequence begins with intrusions as dikes and sills of quartz to normal diabase and gabbro, with norite phases represented by the Nipissing diabase and the Sudbury nickel intrusive. This diabase is separated from the Matachewan quartz diabase by the Cobalt sediments and on the whole is fresher in appearance. Important ore deposits, such as those of nickel-copper, cobalt-silver, and copper, and some smaller lead-zinc deposits are connected with this epoch of igneous activity. The silver-cobalt ores are believed to have been derived from a phase of the diabase magma more alkalic than the diabase itself.[4] Three small gold deposits in the Lake Huron region—the Haviland, Payton and Crystal, have been assigned by Collins[5] to this epoch, since they occur in the diabase and differ from those associated with the Killarney granite nearer the lake. They contain considerable silver, and barite gangue, whereas those with the

[4] Moore, E. S.: Genetic relations of silver deposits and Keweenawan diabases in Ontario. ECON. GEOL., 29: 725–756, 1934, and Bastin, E. S.: The nickel-cobalt-native silver ore type. ECON. GEOL., 34: 39–40, 1939.

[5] Collins, W. H.: North shore of Lake Huron. Can. Geol. Surv. Mem. 143: 116–120, 1925.

granite are highly arsenical quartz deposits. They, and the Bruce Mines copper deposits, which carry some gold and occur in the diabase, may be regarded as being somewhere intermediate in origin between the cobalt-silver and the arsenical gold deposits, the former being derived from a magma relatively richer in alkali and poorer in silica than the latter.

Following the diabase, the Killarney granite was intruded along the North Shore and its injection was accompanied by strong orogeny. It is much more restricted in distribution than the diabase. Many small arsenical gold deposits are genetically related to this granite, which on the whole is a coarse-grained and relatively low-silica type. It produced a goodly number of pegmatites and pegmatitic quartz injections, and some porphyry dikes, but practically no end-phase differentiation products except pegmatites, quartz veins and ore. The granite was followed over a much wider area which is more or less coterminous with that of the quartz diabase, though somewhat smaller, by olivine diabase intrusions, mostly in the form of dikes. These show relatively little metallization and they are very uniform in petrographic character over a large area. It seems difficult to conceive of this olivine diabase representing a differentiate of the granite magma. Its uniformity in character, its extent, and the lack of any regard shown by the intrusions for local structure suggest rather a source in some deep-seated layer such as the postulated basaltic layer.

Algoman.—This system shows a marked contrast to the Keweenawan and Laurentian in the great diversity in rock types and their numerous occurrences in so many different areas. One gets the impression that a very long period of time was involved in the production of these rocks and that they were not all produced in the different areas of the shield at the same time. They should be regarded rather as the result of a series of similar processes operating continuously from area to area through a long period. The nearest approach on this continent to the conditions in the Algoman system seems to be those found in the Sierra Nevada and Coast Range batholiths. In addition to the occurrence of a great variety of rock types, porphyritic texture is a characteristic feature of many of the rocks of this system. These features, and the

number of intrusions in some of the sequences seem to indicate much movement of magma and numerous disturbances in the magmatic chambers. This no doubt was a factor in providing opportunities for escape of the ore-bearing solutions.

In scanning the geological reports previously mentioned, it was found that 65 per cent of the areas described show the presence of Haileyburian or other post-Timiskaming and pre-Algoman igneous rocks with no intervening sediments. In some areas these rocks seem to be so closely related to the Algoman granites that they may readily be regarded as the first phase in a sequence. They are dominantly basic and range from peridotites to diorites. Where such rocks precede the granites there is a strong tendency for basic rocks in relatively small volume to reappear in the later phases of the sequence, whereas the later phases are generally acid, where the sequence begins with acid rocks as it does in about 35 per cent of the areas.

In a previous paper [6] it has been pointed out that the great majority of the batholiths consist of two types of granite, an earlier, gray, somewhat more basic type forming an outer zone with a reddish and more acid type in the interior. In some places the latter type intrudes the former, but generally there is a gradation, and in all cases they were undoubtedly derived from the same magma. The cause of this difference in sections of the batholith has been explained by different geologists as due to differentiation, and to assimilation of intruded rock. The evidence in most cases seems to favor the former explanation.

In his descriptions of the space relations of these batholiths to the gold deposits, Emmons has demonstrated that no deposits may be expected in the main batholiths where exposed in areas of more than 12 to 15 miles in diameter, because they have been removed by erosion. The veins are assumed to have formed in and around cupolas, domes and other projections on top of the batholith by rising solutions. In the Precambrian areas the gold commonly has been formed from solutions rising upward along limbs of synclines, in roof pendants and other related structures in the

[6] Moore, E. S. and Charlewood, G. H.: Two-granite batholiths in the Precambrian. Trans. Roy. Soc. Can., *27*: Sec. IV, 1933.

troughs between the main, exposed portions of batholiths, but in the vicinity of apparent apophyses of the batholith. Some of these troughs in which the ore deposits originate extend thousands of feet below the original peaks on the batholiths. At what depth then, within the magma, does the rest-magma in which the metals are concentrated develop? It must be very deep, and is it not probable that it escapes more frequently through the thinner shell of crystallized granite in the trough than through the higher reaches of the batholith where the shell would be thicker? It would appear from field relations that the main function of the cupolas and domes is a structural one in producing channelways by intrusion and through squeezing of other rocks around these resistant masses during movements that occur during the last phase of the igneous activity and which accompany ore deposition in so many of the fields.

In addition to the granites there are found in the Algoman diorites, granodiorites, monzonites, syenites, quartz porphyries, feldspar porphyries, aplites, alaskites, albitites, pegmatites, lamprophyres, and in a few areas diabase dikes. In at least three important gold fields albitite dikes occur, and they are associated with either diorite or monzonite intrusions in each case, indicating that they arise from magmas comparatively rich in soda. In several fields the gold-quartz veins are closely related to pegmatites. The syenites are found mainly in dikes and small bosses and not in direct gradational contact with the granites. Aplites and lamprophyres occur together but more comonly not, and the aplites seem to be more common in areas where the granites were not preceded in the sequence by basic rocks. These conditions indicate that the idea of the complementary dikes forming by a simple splitting of magmas into acid and basic counterparts is scarcely valid.

The relation of certain quartz-diabase dikes in some of the Algoman sequences is not so easily explained as that of the other rocks mentioned. There is a large area in Ontario and Quebec, centering roughly near Kirkland Lake, where such dikes are numerous. They were at first thought to represent an independent epoch of igneous activity and designated Matachewan diabase,

although they have never been found separated from the Algoman rocks by intervening sediments. Todd,[7] however, mentions three of these dikes in the Kirkland Lake area, and one of them on the Teck-Hughes property is displaced at least 1300 feet by the fault on which the ore bodies occur. This indicates that the dikes preceded the ore which for various reasons is regarded as Algoman in age. In an unpublished thesis for the University of Toronto, A. W. Derby has presented the results of a field and laboratory study of the igneous rocks of the Kirkland Lake area, and an area extending to the southwest of it. He concludes that there are gradational phases between the Algoman and Matachewan rocks as shown by accessory minerals and field relations. In other areas they give the impression of being quite independent of each other.

These diabases are practically devoid of any evidences of having played a part in metallization. They are generally porphyritic and uniform in character. Like the olivine diabases in the Keweenawan, previously described, they can scarcely be considered end products of the granite magmas as are the lamprophyres. They occur over a large area and seem to have been drawn from a large magma of fairly uniform character. Where they grade into the Algoman rocks there must have been a common center of eruption.

THE RÔLE OF THE LAMPROPHYRES AND OTHER BASIC ROCKS IN ORE DEPOSITION.

The close field relations of lamprophyres and other basic rocks to ore deposits has frequently been observed. In 1925 Spurr[8] pointed out the common occurrence of such rocks in magmatic sequences and postulated a temperature of formation of basic rocks associated with copper-zinc-lead ores as 400–500° C. This is in keeping with recent figures given by Sosman[9] for a peridotite dike cutting coal seams in Pennsylvania. A study of the heating effects of this dike on the coal indicated that the coal could not

[7] Todd, E. W.: Kirkland Lake gold area. Ont. Dept. Mines, 37: Part 2, 1928.

[8] Spurr, J. E.: Basic dike injections in magmatic sequences. Bull. Geol. Soc. Amer., 36: 545–582, 1925.

[9] Sosman, R. B.: Evidence on the intrusion-temperature of peridotites. Amer. Jour. Sci., V, 35–A: 353–359, 1939.

have been heated to more than 550° or to less than 480° C. Since petrographers have considered that dry melts of highly basic rocks require temperatures of about 1900° C. to liquify them, and ore deposits mostly form at temperatures below the maximum mentioned by Sosman, these figures are of special interest to students of ore deposits. Sosman suggests that the peridotite dike may have been intruded as a hot, plastic, fluid mud in which crystals were lubricated by films of liquid.

Hulin [10] has been a strong advocate of the derivation of ores from basic phases of magmas. He concludes, after an investigation of a large number of mining camps, that the minor acid intrusives are generally followed by minor basic intrusives and these by the ores. He has also expressed the opinion that where the basic intrusions are the last in a sequence, gold is late in the paragenesis of the ore deposits and where the acid intrusions are the later formed rocks, the gold is earlier.

In a recent paper, Spurr [11] observes that Hulin's deduction regarding the genetic relations of the ores and basic magmas is difficult to apply and that in many cases no such definite relations are found. It is generally accepted by geologists that gold is almost always late in gold-quartz deposits and Mawdsley [12] has recently discussed several gold camps in the Canadian shield in which the evidence of late gold is quite definite. An examination of the rock sequences in these camps does not appear to show that the presence or absence of basic rocks has affected the situation.

The common occurrence of lamprophyres in the Algoman sequences has been a matter of considerable interest to those who have studied these rocks. In my study of the Algoman sequences, lamprophyres were found in 50 per cent of the areas investigated, and allowance should no doubt be made for the possible failure of the geologist to find such dikes in all cases since they are mostly small and in many places much weathered. They occur more than one and one-half times as frequently as aplites. In three areas

[10] Hulin, C. D.: Metalization from basic magmas. Univ. Cal. Pub. Geol. Sci., 18, No. 9: 233–284, 1929.

[11] Spurr, J. E.: Diaschistic dikes and ore deposits. ECON. GEOL., 34: 41–48, 1939.

[12] Mawdsley, J. B.: Late gold and some of its implications. ECON. GEOL., 33: 194–210, 1938.

they cut the quartz veins and in 35 per cent of the areas they are earlier than the veins but closely related in sequence. In another 28 per cent they are earlier than some of the acid rocks and in an equal number of areas they are among the earliest rocks of the sequences.

The lamprophyres of the Algoman, like those of later geological systems, constitute a group of rocks of quite varied composition. The minettes, or mica-lamprophyres, are the most common, with hornblende types next in order, and augite and olivine varieties much rarer. Vogesite, kersantite, camptonite, and syenitic and diabasic lamprophyres have all been mentioned. Gradations from basic syenite to lamprophyre is found at Kirkland Lake and Cooke [13] has stated that in the Larder Lake area these rocks occur in series, the older dikes being more basic than the younger.

The origin of lamprophyres has received much attention from petrographers. Bowen [14] states that Niggli and Berger, after a special study, concluded that they resulted from remelting of local accumulations of early crystals, thus producing liquids of lamprophyric composition. He indicates that lamprophyres are such a broad and ill-defined group that it is difficult to make a general statement concerning them, to which exception might not be taken. He emphasizes their femic and porphyritic character and alkalic groundmass, and proceeds to show how olivine types might be developed in accordance with the *reaction principle*. According to this principle no liquid of the bulk composition of the rock could be developed but the end product of the process would still give an olivine lamprophyre from early-formed olivine crystals supplemented by alkalic liquid. The suggestion of Sosman for the origin of the peridotite dike in Pennsylvania seems to satisfy the requirements for the origin of the olivine lamprophyres when they occur very late in the sequence, and they may be regarded as having been expelled just before the door of the magma was finally closed.

A consideration of the other types of lamprophyres found so commonly in the Algoman indicates that they fall satisfactorily

[13] Cooke, H. C.: Kenogami, Round and Larder Lake areas, Timiskaming district, Ontario. Can. Geol. Surv. Mem. 131: 43, 1922.

[14] *Op. cit.*, p. 258.

into Bowen's[15] *reaction series,* since biotite should form most abundantly with increasing alkalic character of the solutions, and the hornblende next in order of abundance.

As to the rôle of the lamprophyres and related basic rocks of the Algoman system in the formation of the gold deposits, the evidence points to a situation comparable to that so well described by Buddington[16] in the Ore Deposits of the Western States, where he says "but the hypothesis of any but a subordinate genetic connection between lamprophyres and metallization, except in so far as both are connected with the same magmatic cycle and related structural dynamics, is unnecessary, and is without adequate support at the present time." In Porcupine, the largest gold camp in Canada, there are no basic rocks that one could consider closely related to the gold deposits, and the same is true of other important camps. The fact that the materials forming the lamprophyres escaped from the magma indicates that channelways were also available for the ore-bearing solutions. Further, these rocks commonly exert a marked structural influence in the formation of the gold deposits because of their toughness and lack of fractures, a feature well illustrated at Kirkland Lake and in other gold camps. Dikes of these rocks have served in a number of areas to impound the ore-bearing solutions and increase concentration of gold adjacent to them. The conclusion that one may draw from their occurrence in the Canadian shield is that they, and also the minor acid intrusives, are simply indicators of the progressive steps in the progress of differentiation toward a more alkalic and siliceous magma with simultaneous concentration of the metals. The metals remain in solution to the end of the sequence, to be finally expelled from the magma under great pressure along with the remnants of any other constituents, femic or salic. Whether these are acid or basic does not seem to affect profoundly the results in so far as the gold deposits are concerned, so long as the end products are rich in alkalies and free silica.

[15] *Op. cit.,* p. 59.

[16] Buddington, A. F.: Ore Deposits of the Western States, Lindgren Volume, A. I. M. E., p. 379, 1933.

UNIVERSITY OF TORONTO,
Jan. 6, 1940.

THE GEOCHEMISTRY OF QUICKSILVER MINERALIZATION.

II. PETROGRAPHIC ASPECTS OF THE GEOCHEMISTRY OF QUICKSILVER MINERALIZATION.

ROBERT M. DREYER.

(*Continued from Vol. 35, No. 1.*)

INTRODUCTION.

SUITES of typical ores and associated wall rocks were collected for petrographic study from each of the mines visited. It is obviously beyond the scope and purpose of this paper to attempt a complete petrographic description of ores from every quicksilver deposit. Instead, studies have been made of a large number of thin and polished sections of rocks from typical quicksilver deposits for the purpose of obtaining evidence pertaining to each of the fundamental problems of quicksilver mineralization listed below:

(1) The relation of the various types of wall rock alteration to the quicksilver mineralizing solutions.

(2) The relation of metacinnabar to cinnabar and the type of iron disulphide associated with metacinnabar and cinnabar-bearing ores.

(3) The mode of access of quicksilver mineralizing solutions into the various types of country rock.

Petrographic evidence pertaining to each of these problems will be discussed in the following pages.

RELATION OF WALL ROCK ALTERATION TO QUICKSILVER MINERALIZATION.

The degree of wall rock alteration accompanying quicksilver mineralization varies within wide limits. Some of the deposits occurring in sandstone show notably little alteration. Conversely,

the silicification accompanying cinnabar deposition in serpentine is so marked that the silicified serpentines have been given the name "quicksilver rock." In other deposits, the predominant alteration is carbonatization and some deposits exhibit intense kaolinization. Since both cinnabar and silica are soluble in alkaline sulphide solutions, it would be expected that there would be a close genetic relationship between cinnabar and silica deposition. Conversely, alkaline earth and carbonate ions cannot exist together in alkaline solutions and hence carbonate vein filling must be related to acid rather than to alkaline solutions. Thus, the presence of carbonatization would seem to necessitate a temporary change in the character of the mineralizing solutions and a temporary cessation of cinnabar deposition during the course of mineralization.

Probably nowhere is the relation between cinnabar and silica deposition shown more clearly than in the Goldbanks deposit.[1] A prominent feature of this district is a series of silica hot spring deposits forming a linear, northward-trending zone about two and one half miles in length and averaging about one half mile in width. The silica deposits occur near the contact of Quaternary (?) basalt with Permian (?) coarse clastics and volcanics. The mineralization is believed to be very recent and to be directly related to the period of basaltic extrusion. The silica deposits form a gently westward dipping cover (never more than 100 feet in thickness) over a mature topography. On account of this mode of occurrence, the deposits have been given the descriptive name "silica apron."

Near the southern end of the apron zone, cinnabar is disseminated through the silica. The cinnabar occurs in two zones about three feet apart and varying up to seven feet in thickness. The two cinnabar-bearing zones follow the gentle, westward dipping stratification of the silica apron. Nowhere has the cinnabar been found below these zones. In many places, the cinnabar occurs in dense silica beneath more porous layers of the apron. The field relations thus indicate a syngenetic deposition of cinna-

[1] Information on the Goldbanks deposit, Nevada, published by permission of the Director, Geological Survey, U. S. Dept. of the Interior.

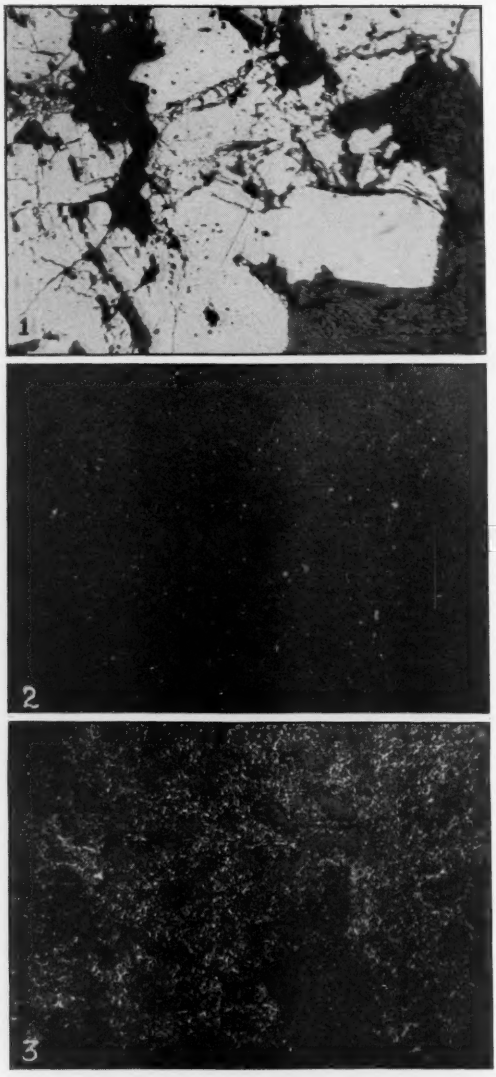
bar and silica. The cinnabar, however, occurs in only one small portion of the total silica apron zone and there in only two horizons in the apron. In other words, from only one of a series of closely related thermal springs was cinnabar deposited and there during only two stages of the hydrothermal activity.

The material of the apron consists essentially of quartz and chalcedony. Minor amounts of opal form the linings of a few microscopic vugs. The apron has a highly fragmental appearance, but, in only one area, where the siliceous waters flowed out over rounded, fluvial gravels, is there any considerable amount of exotic material in the apron. In the remainder of the apron, the fragments consist entirely of re-worked hydrothermal silica distinguishable by differences in color. These fragments have been formed by continued dehydration, cracking, weathering, re-working, and re-cementation of the hydrothermal silica. Microscopically, the cinnabar occurs as dispersions through silica cement and through colloformally banded silica veinlets. The maximum concentrations of cinnabar generally occur along the contacts of the corroded silica fragments. The cinnabar-silica cement has been re-fractured and re-cemented by more cinnabar-silica cement. The net result of this process of continued cracking, re-working, and re-cementation is the cinnabar ore as it is now found consisting of silica fragments in a matrix though which is dispersed abundant cinnabar, the whole being cut by still later silica containing more dispersed cinnabar.

In summarizing the mode of formation of the Goldbanks ore, the following stages are separated with the understanding that the entire process occurred simultaneously in various portions of the deposit: (1) deposition of silica by a number of thermal springs; (2) dehydration and crystallization of the silica with consequent cracking; (3) accentuation of the brecciation by weathering and reworking of the fragmental material by the spring waters; (4) cementation of the fragmental silica by solutions carrying silica and, locally, mercuric sulphide. The cinnabar was probably precipitated as a result of decreased solubility resulting from a relief of pressure and evaporation at the surface; (5) repeated cracking and brecciation and subsequent re-cementation of the rock by

cinnabar-silica cement resulting in the formation of an ore containing barren silica fragments in a silica cement through which is dispersed much cinnabar, the whole being cut by many later veinlets containing silica and more dispersed cinnabar.

Another evidence of the marked syngenesis of cinnabar with silica is the fact that the cinnabar is not merely a dissemination, but rather is actually a dispersion through the silica. Thin sections of cinnabar ore tend to overemphasize the size of the cinnabar aggregates because the thinness of the section and the fact that the section is examined in transmitted light make it impossible to see any third dimension of the individual grains. On the other hand, a study of polished sections in reflected light gives some idea of the three dimentional size of the cinnabar grains since the individual grains will not take a polish unless they are above some definite size. Ordinary cinnabar when polished shows a soft, metallic surface (Fig. 1). Goldbanks cinnabar, however, characteristically shows no such metallic surface (Fig. 2). Ore above 2 per cent shows small metallic areas although by far the greater portion of the cinnabar in the section has a non-metallic surface (Fig. 3). Megascopically, and under obliquely reflected light, such cinnabar ore that shows a non-metallic surface appears bright red and in places appears to be nearly pure cinnabar. The polished surface, however, is not only non-metallic, but is also hard. The surface polished is thus a silica surface and the cinnabar is dispersed through the silica in so fine a state of subdivision that, except in the very highest grade ore, none of the cinnabar is in aggregates large enough to show a polish. This state of dispersion has given to an ore, the maximum cinnabar content of which is not over 7 per cent, the appearance of being nearly pure cinnabar. The color of the cinnabar is most pervading and, for this reason, it is necessary to use the utmost care in the megascopic estimations of cinnabar concentrations since the color of a hand specimen depends not only on the total cinnabar content, but also on the state of subdivision and degree of dispersion of the cinnabar through the ore. Some of the Goldbanks ore was crushed to — 125 mesh and concentrated. The concentrate appeared to be nearly pure cinnabar. The concentrate was mounted



FIGS. 1–3.

in an immersion oil of index 1.620. This liquid was chosen so that its index would be far from the indices of the minerals that might be present in the concentrate—namely, cinnabar, quartz, and chalcedony. Although all of the concentrate was bright red and appeared to be nearly pure cinnabar, nearly all of the grains showed an index below 1.620. The cinnabar is thus again shown to be clearly a dispersion through the silica and the pervading color of the cinnabar has caused the cinnabar-silica dispersion to appear like pure cinnabar. In order to ascertain the order of magnitude of particles that would not polish with a metallic surface, cinnabar powder prepared by sublimation and chemically precipitated cinnabar were mounted in separate bakelite mounts and polished. The powder was nearly all finer than 200 mesh. In spite of the difficulties inherent in the polishing of soft powders, both of the cinnabars polished with metallic surfaces. The size of the cinnabar particles dispersed through the silica must thus be considerably less than 200 mesh. This extremely fine state of cinnabar subdivision must indicate a very marked change in the physical environment of the solutions on reaching the surface. Only a very marked change in the physical environment could account for the rapid precipitation necessary to produce so high a degree of dispersion. Schuette [2] has noted a similar dispersion of cinnabar through silica in ore from the Opalite mine in southeastern Oregon.

The cinnabar deposits occurrying in serpentine have been highly silicified. In these deposits, there has also been some carbonatization so that it is here possible to study the relation of cinnabar

[2] Schuette, C. N.: Quicksilver in Oregon. Ore. Dept. of Geol. and Min. Ind., Bull. 4: 151–2, 1938.

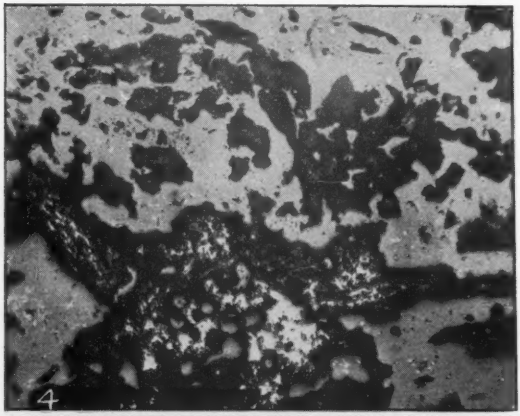
FIG. 1. Polished section of cinnabar from Klau mine showing typical metallic surface. × 105.

FIG. 2. Polished section of high grade Goldbanks ore (1 per cent) showing silica surface with only a few small cinnabar aggregates large enough to show a metallic surface. The entire field is bright red megascopically and in obliquely reflected light. × 105.

FIG. 3. Polished section of very high grade Goldbanks ore (4 per cent) showing small metallic areas in a non-metallic field. The entire field is bright red megascopically and in obliquely reflected light. × 105.

mineralization not only to silicification, but also to carbonatization. In polished sections, it is possible to recognize two types of gangue—the soft gangue minerals, that are carbonate and serpentine and the hard gangue minerals that are silica—quartz and chalcedony. Here again, much of the bright red cinnabar polished with a hard, non-metallic surface although megascopically, under obliquely reflected light, and in transmitted light the ore can be seen to contain abundant cinnabar. The cinnabar is here again dispersed, in a very finely divided state, through the silica. Notable, however, is the fact that such dispersed cinnabar occurs only in the silica and not in the carbonate or serpentine. In fact, it is often possible in polished section to distinguish areas of hard gangue from those of soft gangue merely by noting where the cinnabar is wholly or partly dispersed and where all of the cinnabar polishes with the typical soft, metallic surface. All of the cinnabar in carbonate or serpentine is in aggregates coarse enough to show a metallic surface. It is only in the silica (quartz and fibrous chalcedony) that some—but not all—of the cinnabar occurs in dispersions too fine-grained to show a metallic surface (fig. 4). The cinnabar is, of course, known not to be syngenetic with the serpentine and the evidence here presented corroborates the evidence obtained by geochemical experimentation—namely, that cinnabar may be deposited syngenetically with silica, but cannot be deposited syngenetically with carbonate. The presence of carbonate in quicksilver deposits must indicate a temporary cessation of quicksilver mineralization and an influx of acidic carbonate waters during the period of hydrothermal activity.

Cinnabar which is in so fine a state of subdivision that it will not show a metallic surface when polished is not confined wholly to silicified rocks, but may also be the result of a very lean, fine-grained dissemination. At the Cuddeback mine the cinnabar occurs as streaks that cut highly kaolinized rhyolite. The cinnabar streaks are distinctly visible both megascopically and in oblique illumination, but only a very small portion of each streak generally gives a metallic polished surface. An examination of a concentrate of the ore reveals that the cinnabar is only a very thin coating over the kaolin grains. Since the cinnabar is a coat-



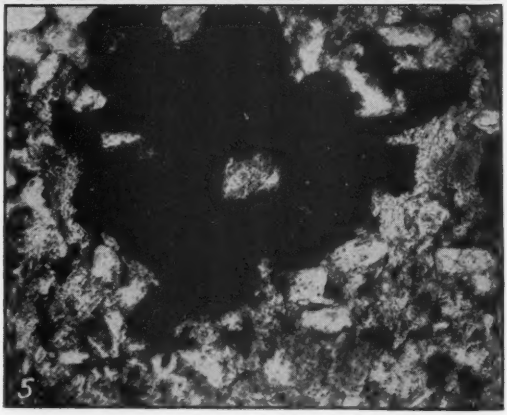


FIG. 4. Polished section of cinnabar ore in silicified serpentine from open pit at Aetna mine. Metallic cinnabar replacing unaltered serpentine (black) and non-metallic cinnabar dispersed through silica (light grey). All of the light grey silica areas are bright red both megascopically and in obliquely reflected light. × 105.

FIG. 5. Thin section of ore from Oceanic mine showing characteristic large cinnabar aggregate replacing fine sandstone grains. × 120. Plain light.

ing over the kaolin in the Cuddeback deposit, the kaolinization has apparently preceded the quicksilver mineralization.

The close relationship of cinnabar and silica deposition is apparent in many deposits. Carbonatization and kaolinization, however, are not so closely related to the deposition of cinnabar and, at least insofar as concerns carbonatization, it is deductively most difficult to see how cinnabar and carbonate could be deposited from the same solutions. The presence of cinnabar in only one small portion of a series of strikingly similar silica hot spring deposits in the Goldbanks district indicates that the heavy metal content of thermal springs varies widely during a given period of mineralization. Similarly, there is no reason to believe that the alkalinity and general elemental content of thermal waters should likewise not vary widely during a period of mineralization and that the various mineral components should not be deposited at different times.

TYPE OF IRON DISULPHIDE ASSOCIATED WITH QUICKSILVER DEPOSITS.

The type of iron disulphide that can be deposited from quicksilver mineralizing solutions is directly related to the temperature and acidity of the solutions and these factors, in turn, determine the type of mercuric sulphide that is deposited. Cinnabar is deposited only from alkaline solutions and metacinnabar only from neutral or acid solutions at low temperatures. Marcasite is deposited only from acid solutions at low temperatures, but some pyrite is deposited in acid as well as alkaline solutions. At the temperatures of quicksilver mineralization, both pyrite and marcasite are stable in any solutions after once having been formed. In a new influx of alkaline sulphide solutions, metacinnabar will be wholly or partly converted to cinnabar. Thus, the occurrence of cinnabar, metacinnabar, pyrite, and marcasite together is not anomalous. However, unless all of the cinnabar has been converted from metacinnabar, the association of marcasite and cinnabar alone must indicate that the two sulphides were deposited at different times. If the cinnabar has been converted from metacinnabar, it would be expected that some metacinnabar remnants

would be visible in the ore. Metacinnabar, however, is notably absent from most quicksilver ores. The paragenetic relations of iron disulphide to mercuric sulphide are difficult to determine petrographically not only because of the relative scarcity of metacinnabar, but also on account of the strong crystallizing power of the iron disulphides which makes it difficult to ascertain whether euhedral crystals are earlier or later than the adjacent ore and alteration minerals.

The writer was fortunate to visit the Mount Diablo mine at a time when much of the ore consisted of a mixture of metacinnabar and cinnabar with much pyrite and marcasite. Much of the pyrite and marcasite occurs as vein fillings cutting the mercuric sulphides and as crustifications over the mercuric sulphides. It would thus appear that at least a portion of the iron disulphide is post-mercuric sulphide. The iron disulphides are very intimately related and must have been deposited at essentially the same time. Many specimens show beautifully banded iron disulphide. Such colloform bands often consist of both pyrite and marcasite and the intimate association of the two minerals is likewise shown by the occurence of either one of the iron disulphides enclosed within areas of the other. The relationship of cinnabar to metacinnabar is likewise most intimate—metacinnabar occurs within cinnabar and cinnabar occurs within metacinnabar to give a most intimate mixture. Cinnabar and metacinnabar, unlike pyrite and marcasite, cannot be deposited from the same solutions except at very low temperatures so that this intimate relationship must indicate a partial conversion of the monotropic metacinnabar to cinnabar by later alkaline sulphide solutions. That such an inversion has occurred is indicated by the anomalous anisotropism of much of the metacinnabar. This anisotropism must be attributed to the incipient inversion of some of the isometric metacinnabar. A remarkable feature of polished sections of metacinnabar and cinnabar is that polished surfaces of the former are much smoother than those of the latter. This effect has been noted by Short[3] and is so pronounced in the Mount Diablo

[3] Short, M. N.: Microscopic determination of the ore minerals. U. S. Geol. Surv. Bull. 825: 96, 1931.

polished sections that it is possible to distinguish the two mercuric sulphides solely by the character of the polish. In the Mount Diablo deposit, then, although the mineral assemblage is of a type that chemically might indicate simultaneous deposition of the iron and mercuric sulphides, nevertheless, the crustifications and veins of the iron disulphide through mercuric sulphide would indicate that at least a portion of the iron disulphide is later than the mercuric sulphide.

All of the iron disulphide in specimens from the Aurora mine is marcasite although no metacinnabar is present in the ore. Unless the cinnabar has been derived from a complete conversion of the metacinnabar that has not left a trace of metacinnabar, this association must mean that the marcasite and cinnabar have not been deposited simultaneously from the same mineralizing solutions. The cinnabar in the Aurora mine is largely dispersed through syngenetic chalcedony which has replaced the serpentine. The marcasite commonly replaces this cinnabar-silica mixture. The marcasite generally occurs in well-formed euhedral crystals scattered through the silica. The fact that euhedral marcasite crystals are scattered through highly silicified country rock through which is dispersed much cinnabar makes it appear certain that the marcasite deposition was distinctly separate and later than the syngenetic deposition of cinnabar and silica.

Cinnabar likewise occurs only with marcasite in specimens from the Great Western and Klau mines; it occurs with both pyrite and marcasite in the Bradford, Oceanic, New Idria, and Sulphur Bank mines. The common occurrence of cinnabar with marcasite (in the absence of metacinnabar) makes it appear that much of the iron disulphide deposition has been accomplished at a period of the mineralization distinct from the period of quicksilver deposition and often at times when the mineralizing solutions were somewhat acid and thus capable of depositing marcasite. Like carbonatization, and perhaps kaolinization (but unlike silicification), the deposition of iron disulphide apparently has not been accomplished by the same solutions that deposited the mercuric sulphide although the entire mineralization is undoubtedly related to one period of hydrothermal activity during

which the character of the mineralizing solutions varied considerably.

MODE OF ACCESS OF QUICKSILVER MINERALIZING SOLUTIONS.

Becker[4] has stated that all cinnabar in sandstone occurs as impregnations of intergranular voids and that, in other types of rocks, the cinnabar occurs filling fractures or other types of openings. Becker denied the existence of any replacement of wall rock by the quicksilver mineralizing solutions. An examination of Becker's reasoning shows that he was influenced more by erroneous deductions than by actual petrographic evidence. Becker could not understand how solutions which, in some places, themselves deposited silica could likewise be capable of dissolving silica to provide new depositional loci for the cinnabar. In the light of theories of chemical equilibrium such as are now recognized, but which were not understood in Becker's time, it is known that a solution which may be undersaturated with respect to silica at one time may later become saturated with silica and re-deposit the silica at another point. One and the same solution is thus capable both of dissolving silica and thus providing depositional loci for the cinnabar and, at the same time, of silicifying the country rock. Even saturated solutions in equilibrium continually dissolve and re-precipitate to maintain the necessary equilibrium. In Becker's time, replacement was believed to consist in the solution of a molecule of one substance and the corresponding deposition of a molecule of the second substance rather than the present concept of large scale solution and re-deposition. Since Becker regarded replacement as a process of molecular interchange, he believed that cinnabar should be pseudomorphous after any wall rock constituents that were replaced. In the absence of pseudomorphs of cinnabar after rock-forming minerals, Becker felt that replacement could not have occurred. The absence of such pseudomorphs is no proof of the absence of replacement and many quicksilver deposits show evidence of abundant replacement.

[4] Becker, G. F.: Quicksilver deposits of the Pacific Slope. U. S. Geol. Surv. Mon. 13: 30, 315, 394–401, 1888.

One of the ores in which Becker stated that no replacement had occurred is that of the Almaden mine in Spain. Becker stated that the Almaden occurrence was solely an impregnation of the intergranular voids of the sandstone and that there was no replacement of the sandstone grains. Ransome [5] undertook a study of the occurrence of cinnabar in sandstone at Almaden. By showing that the Almaden ore grades all the way from lean specimens in which the cinnabar is only an impregnation of the sandstone voids into specimens in which there are large areas of nearly pure cinnabar in the sandstone with only occasional sandstone residues, Ransome proved that there has been abundant replacement of the sandstone in those portions of the sandstone where there is an excess of cinnabar. Similarly, the writer has studied a large number of occurrences of cinnabar in sandstone and other types of wall rock. There is some replacement in all types of wall rock and, in high grade ore occurring in sandstone, there often is a large scale replacement of the component sand grains. A notable feature of quicksilver mineralization, however, is that the first stages of mineralization always involve a filling of fractures or, in sandstones, of the intergranular voids. It is only when the cinnabar is locally in excess that the cinnabar begins to replace the wall rock constituents. Nevertheless, in the examination of occurrences of cinnabar in various types of wall rock, the writer has yet to see a quicksilver deposit in which there has not been some replacement and in many places the amount of replacement is considerable.

The ore of the Oceanic mine is particularly indicative of considerable replacement of the sandstone grains by cinnabar. A peculiarity is that the cinnabar is not a fine-grained dissemination through the sandstone such as could be attributed to the impregnation of the intergranular voids, but occurs rather as sparsely scattered aggregates most of which are many times the size of the component sand grains and of the intergranular voids. For such cinnabar aggregates to have attained their present size, there must have been some replacement and the ragged outlines

[5] Ransome, F. L.: The ore of the Almaden mine. ECON. GEOL., 16: 313–21, 1921.

of the sandstone grains adjacent to the cinnabar likewise attest to such replacement. Some of the Oceanic ore is of especial interest since it illustrates exactly what Ransome noted in the Almaden ore—namely, that in the same sandstone, the lean disseminations of cinnabar occur as impregnations and cement replacements, but that, in the portions of the sandstone in which there is a large concentration of cinnabar, there has been much replacement of the sandstone grains. One portion of a polished section will show a lean impregnation and replacement of the sandstone cement, but another portion of the same section will show large areas of the sandstone almost completely replaced by cinnabar. Likewise, there are areas where much, but not all, of the sandstone has been replaced and there are many ragged grains as well as isolated sandstone remnants within the cinnabar. Fig. 5 shows one of the relatively large aggregates replacing the sandstone grains.

A portion of the ore at New Idria occurs disseminated through sandstone. In the low grade portions of the ore, the cinnabar has gained access by impregnation and by a replacement of the cement. There has been corrosion and replacement of the individual grains only in the portions of the ore in which there is a relatively great concentration of cinnabar. A large portion of the ore at New Idria occurs in apparently sharp-walled veins in a dense slate. An examination of thin sections of this ore shows that there has been much dissemination through and hence replacement of the dense slate.

Some of the ore at Sulphur Bank occurs as a dissemination through lacustrine gravels. In the higher grade ore there has been much corrosion of the gravel pebbles by the cinnabar, but it is noteworthy that, here again, the cinnabar has first gained access by impregnation and by a replacement of the cement. Corrosion and replacement of the pebbles are features only of those portions of the ore that have a relatively large cinnabar content and where the cinnabar content thus exceeds the capacity of the available intergranular spaces (Fig. 6).

A large portion of the ore at Sulphur Bank occurs in a dense

basalt. The cinnabar occurs in veinlets which, megascopically, appear sharp-walled. However, in detail, the outlines of the veinlets are most ragged (Fig. 7) and there has been an amount of replacement by the veinlets, which is large relative to the size of the veinlets. Here again it is to be noted that the solutions have followed fractures until such fractures have been filled. The cinnabar is then forced to corrode and replace the country rock. Mention has already been made of the occurrence of cinnabar in serpentine. Such cinnabar is by no means confined to fractures. The greater part of the cinnabar is confined to portions of the serpentine which have been replaced by quartz and fibrous chalcedony, but some cinnabar is likewise disseminated through unaltered serpentine.

The wall rock at the Klau mine is a dense shale. Most of the cinnabar occurs as crustifications and fracture fillings, but dissemination and replacement are present on a small scale. Similarly, the ore at the Cuddeback mine occurs in a highly kaolinized rhyolite—so highly kaolinized that only the quartz blebs of the original rock remain. Cinnabar veins cut through the kaolin and, only locally, are these veins sharp-walled. Generally there has been abundant wall rock replacement.

There can be no doubt that, in the first instance, quicksilver mineralizing solutions have gained access into the country rock through intergranular openings and fractures. The occurrence of cinnabar in such openings and fractures commonly accounts for by far the greater percentage of cinnabar in the ordinary quicksilver ore. However, whenever the concentration of cinnabar in any small area becomes so great that the available openings are filled, the cinnabar-bearing solutions are quite capable of replacing components of the wall rock and such replacement is by no means an uncommon feature of quicksilver ores. Replacement of grains and pebbles of sandstone is particularly common and, even in the densest rocks such as basalt, slate, and serpentine, there has been some replacement of the wall rock components by the cinnabar.

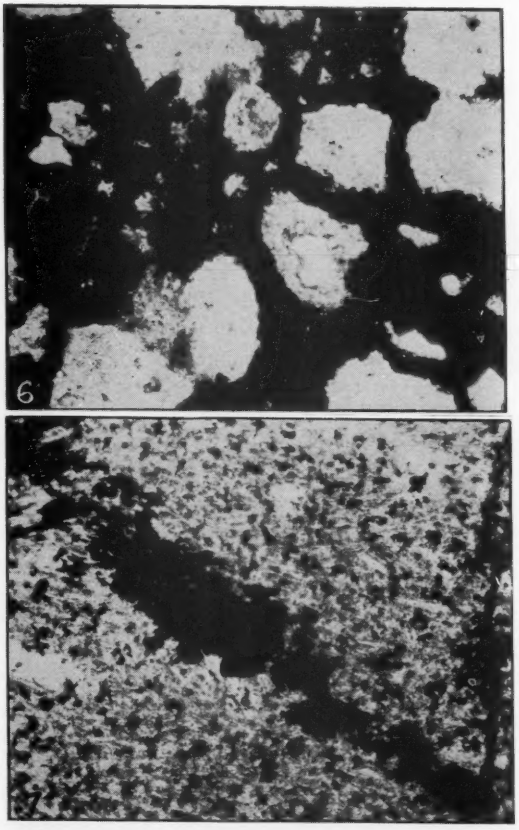


FIG. 6. Thin section of ore from open pit of Sulphur Bank mine showing large cinnabar aggregates replacing lacustrine gravel pebbles. Note the ragged, corroded pebbles and the residual grains in the cinnabar. × 120. Plain light.

FIG. 7. Thin section of ore from open pit of Sulphur Bank mine showing straight replacement veinlets with ragged boundaries cutting basalt. × 120. Plain light.

SUMMARY.

Cinnabar can be deposited only from alkaline sulphide solutions. Mercuric sulphide and sulphide ions are in equilibrium with the soluble mercuric sulphide complex. The solubility of cinnabar is thus dependent solely on the sulphide ion concentration which is, in turn, partially dependent on the alkalinity of the solution. Such alkaline solutions are capable of dissolving silica, but carbonate and alkaline earth ions cannot exist together in such alkaline solutions. Any carbonatization of quicksilver deposits must thus represent a stage in the period of mineralization distinct from the period of cinnabar deposition. However, silica is commonly deposited syngenetically with cinnabar and the relationship of cinnabar and silica (unlike that of cinnabar and carbonate) is so intimate that the cinnabar occurs, in some places, as an extremely fine dispersion throughout associated silica.

The cinnabar-bearing solutions gain access into the wall rocks through fractures and intergranular voids and the greater part of all cinnabar ores is the result of such open-space filling. When the openings become filled, however, the solutions are quite capable of replacing the adjacent wall rock. If the wall rock is out of equilibrium with the quicksilver mineralizing solutions, the adjustment of equilibrium and consequent precipitation of mercuric sulphide will be quite rapid.

Precipitation of cinnabar is caused primarily by relief of pressure, evaporation of solvent, and wall rock reaction. Except in ammoniacal solutions, a decrease in temperature will not cause precipitation. Dilution of solutions causes the precipitation of metacinnabar and colloidal mercury. Such dilution is probably responsible for the native mercury, which is a common, minor component of many quicksilver deposits. Acidification will likewise precipitate metacinnabar, but not cinnabar. The infrequent occurrences of metacinnabar can best be explained by near-surface dilution or acidification of hypogene solutions. Insofar as temperature and alkalinity are concerned, pyrite or both pyrite and marcasite could be expected to occur with cinnabar or metacinnabar or both. However, where marcasite occurs with cinna-

bar alone (as is quite commonly the case), the marcasite has probably been deposited at a period distinct from the period of cinnabar deposition. Since cinnabar (rather than metacinnabar) is deposited only from hot alkaline solutions, supergene deposition of cinnabar must be a very local and a very uncommon occurrence.

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THE PEGMATITES OF THE SPRUCE PINE DISTRICT, NORTH CAROLINA.

C. S. MAURICE.

(*Continued from Vol. 35, No. 1.*)

PART II.

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Group V. Miscellaneous Pegmatites, Aplites and Other Rocks.

In order to present the facts as completely as possible, the following phenomena are mentioned although no general conclusions are deduced from them: (1) Kyanite bearing pegmatites and kyanite-quartz bodies; (2) Beryl- and tourmaline-bearing pegmatites not previously classified; (3) Fine grained oligoclase-quartz-microcline intrusives with oriented mica flakes; and (4) Sugary textured aplites and other relatively fine grained but irregular textured intrusives consisting mainly of plagioclase and quartz. The composition of the plagioclase of some of the pegmatites is plotted on Map A.

Kyanite.—Numerous veins and pockets carrying kyanite occur in lenses of kyanite gneiss within the Carolina gneiss series. They consist mainly of quartz, kyanite, and feldspar, with any one of the constituents predominating locally. Of the feldspars, oligoclase (An 22 to 30) appears most abundantly, and potash feldspar is generally wanting. The distribution of these bodies

and their composition and genesis have been described by Keith (20, p. 2), Fessler and McCaughey (7), and Stuckey (41).

Beryl and Tourmaline.—A number of pegmatites containing beryl and tourmaline not classified in Groups I to IV have been plotted and studied. Some contain emerald, aquamarine, amazonite, and magnetite.

Fine-grained Foliates.—A few oligoclase-quartz dikes, with muscovite and very small amounts of microcline, transect pegmatites. The plagioclase contains 15 per cent An. These rocks have a well developed foliation.

Aplites and Similar Rocks.—Sugary textured aplite is notably rare in the district (189, 265). Other rocks with more irregular texture and variable proportions of quartz and plagioclase are included. None of these contain any potash feldspar. Perhaps to be compared with them are the small irregular veins of coarser oligoclase (An 15) and quartz, occurring in massive quartz at the Phillips mine, No. 91, and the Deer Park mine, No. 235, both in Group IV–A.

Paragenesis in the Magmatic Stage.

The age relationships of some of the subgroups of pegmatites afford strong evidence of the crystallization sequence in the magmatic stage. Structural features confirm this evidence and furnish additional information. Most noteworthy in the paragenesis is the early magmatic stage of plagioclase. This conclusion is basic to the succeeding section, Replacement in Stage 2-a.

Table I presents the composition of the plagioclase, in terms of the percentage of the anorthite molecule, found in different members of the various sub-groups. The potash feldspar content of these has already been defined. It will be seen that a majority of the calcic-oligoclase pegmatites contain little or no potash feldspar. Examples of pegmatites containing an intermediate plagioclase, An 19 to An 15, are distributed between Groups I–B and IV. Finally, neglecting Group V, most examples of pegmatites having plagioclase less calcic than An 15 fall in Group IV. More than one hundred normal pegmatites are included,

TABLE I.

% An.	IA.	II.	IIIA.	IIIB.	IIIC.	IB.	IC.	(a).	IVA.	IVB.	IVC.	V.
30	117											325
29		136	354									
		320										
28	441		251									15
	37		412									
27	439		241			288						
				51								
26	91											
25	130	170		92								171
		187										
24	329	442			278					38		
		283										
23	11			48								18
	101			296	272					277		
				426								
22	330		249	41		287						413
				415								
21						432		21%	432			
						446						
20	37			54					437			
	141			231								
	308							20%	235*			
	436											
19						440						
						118						
						445						
18				20*		258				422	93	
						449						
17						95		26%	91	14		291
16						101				429	109	
						232					307	
						247						
						444						
15						416	135		2*	113	420	113
						467		20%	141*			138
								20%	438			229
												231
14				47*			131		181			
									269			
13									418	312*		
									437			
									29			
						49		13%	49			
									448			
12		353				447		17%	119		270*	265
11									4			
									8			
									13	252		314
								18%	433			
10				185*							58*	
				310								
9									94			
8									146			
									311			
7									52		6	143
												189
6												262

(a) Percentage of An in plagioclase of the common pegmatite in which the Group IV pegmatite occurs.

* Indicates the presence of an additional, more sodic, plagioclase.

counting shoots separately. The larger proportion of potash feldspar associated with the more sodic plagioclase is readily apparent.

The occurrence of Group IV pegmatites as shoots and dikes in common pegmatites demonstrates that in *certain* types of cases the pegmatites with larger proportions of perthite, and more sodic plagioclase, are younger than those of contrasting composition. Moreover, the pegmatitic magma of the above shoots and dikes have been differentiated from the enclosing common pegmatite. The evidence for this conclusion is: (1) The plagioclase of shoots is never more calcic than the plagioclase of the common pegmatite, and in most cases is not more than six units more sodic. (2) Many common pegmatites show the effects of stress that suggest filter-pressing. (3) Many shoots fail to continue with depth. The inference that plagioclase started crystallizing before potash feldspar seems inescapable.

That the above conclusion should be extended to the whole series of pegmatites is suggested by the essential unity of the series as emphasized below.

Table I presents a considerable range in the composition of the plagioclase of any one group. As already indicated, Group I–A grades into Group III–A with increase in the proportion of commercial sheet mica; the textures of both are variable but similar. Group I–A grades into Group II with increase in the degree of segregation of the quartz, which tends to accompany the increase in grain size. Group III–A grades into Group III–B with increase in percentage of potash feldspar. Between subgroups A and B of Group I there is a sharp break in the composition of the plagioclase and also in the texture of the muscovite; however, the plagioclase-quartz-perthite portions of some of the mines in Group III are similar in texture to common pegmatites (Group I) and suggest a continuation of the latter into the calcic oligoclase range. The members of Group IV–B also suggest a tie across this line of discontinuity, as far as the composition of the plagioclase is concerned. Group I grades into Group IV by increase in the proportion or grain size of perthite free of intergrown quartz; on the other hand, by increase

in metamorphism, examples which might otherwise be classable as Group IV become unproductive and are classed with Group I. The contacts bewteen Group IV–A and the common pegmatite in which they occur are seldom well exposed, but in general appear to be gradational.

Grain size does not help to distinguish pegmatites that are also different in other respects; each group shows a great range in primary grain, overlapping the sizes of other groups.

There is, on the other hand, some systematic variation in the type or degree of foliation found in the different sub-groups of Group I; however, the variation within a single sub-group indicates that the deformation varied locally, even to the extent of affecting only certain portions of a given pegmatite, so that this feature cannot be used as a criterion for distinguishing unrelated groups.

Table II, showing the paragenetic relations in the magmatic stage, is presented as a basis for the discussion below.

TABLE II.

PARAGENETIC RELATIONS.

Components.	Without Complete Segregation.	Segregation Possible.
		Diag. 1.
Calcic Oligoclase		———
Muscovite		—
Quartz		———
		Diag. 2.
Calcic Oligoclase		———
Quartz		———
Perthite		—
Muscovite		—
	Diag. 3.	Diag. 4.
Sodic Plagioclase[a]	———	———
Quartz	——— ——	———
Perthite	——	——
Muscovite		—

[a] Consisting of sodic oligoclase and calcic albite, An 5 to An 15. For diagram 3, An is probably close to 10. Conditions intermediate between types 2 and 3 exist and between types 3 and 4.

[b] Biotite, rare.

In certain calcic oligoclase pegmatites (Groups II to IV), the perthite is confined to the middle of the pegmatite, or is more

abundant there. This indicates that in extreme cases, perthite did not begin to form until after the separation of oligoclase was complete (Diagram 2). Some of the more sodic plagioclase pegmatites (Group IV), at least as coarse grained as the segregated ones referred to above, lack separation of the plagioclase and perthite; this would imply more overlap of perthite and albite, provided the power of diffusion were the same (Diagram 3). However, in some sodic plagioclase pegmatites, banded structures indicate relations similar to those in calcic oligoclase pegmatites (Diagram 4). Conditions intermediate between those of diagrams 2 and 3 and between 3 and 4 doubtless exist. That the eutectic condition of diagram 3 does actually exist is further indicated by the presence of plagioclase in large proportions in *all* of the large shoots of Group IV; if perthite were still in solution after the crystallization of plagioclase, in the common pegmatite, then perthite-quartz pegmatites might be expected as the end members of the series. These occur only on a very small scale. The eutectic proportions for Or, Ab, and An for such pegmatites would be those occurring in perthite. For some calcic oligoclase pegmatites it is possible that the quartz and perthite lines of diagram 2 should be continued farther to the left.

The above evidence from a number of well segregated pegmatites confirms the statement that plagioclase tends to start crystallizing before potash feldspar, but indicates much difference in the amount of overlap in different cases.

The paragenetic relations of quartz vary even in pegmatites of the same group. Quartz may appear soon after the first oligoclase, or not until after all other minerals have ceased forming. In some cases the crystallization of quartz may have been discontinuous.

As shown by the tendency for quartz to be segregated from calcic oligoclase in many medium to coarse-grained pegmatites, it is relatively late forming in pegmatites of Groups II and III (Diagram 1). Quartz intergrowth in calcic oligoclase is rare.

Although, in some coarse-grained sodic oligoclase pegmatites, quartz forms central masses sharply separated from the feldspars and is obviously late (Diagram 4), in others of medium

to coarse grain it is intergrown with the feldspars in a regular texture that is believed to be primary (Diagram 3).

A comparison of the amount of quartz in some shoots with that in the surrounding "parent" pegmatite shows that silica was not being concentrated to any great degree by crystallization of sodic oligoclase in the common pegmatite. Contrast with this the concentration of K_2O under the same conditions. This conclusion, however, is jeopardized by the possibility that much of the silica originally in the shoots may have been squeezed off.

Primary muscovite, like the potash feldspar, tends to be concentrated toward the middle of the pegmatites. But where there is a distinct quartz midriff, the muscovite is found at and near the feldspar and quartz contact. See also above, Group IV, *Inner Structures*. In crystallization sequence it therefore appears to overlap the feldspars at one end and the quartz at the other, as shown in diagrams 1, 2, and 4.

Biotite occurs in comparatively few pegmatites, mostly in areas where the Roan gneiss predominates in the country rock. In the magmatic stage it is an early mineral, associated most intimately with oligoclase and muscovite. The latter frequently forms an outer zone around the biotite crystals.

Replacement in Stage 2-a.

In this section the origin of certain features previously mentioned under the head Texture *f*, some of which suggest replacement of perthite by plagioclase, especially by albite, is discussed. The present condition of the plagioclase involved is concluded to result from metamorphism of primary plagioclase, and part at least of the muscovite involved doubtless owes its potash to preexisting microcline and is also metamorphic. A part of the associated quartz has replaced the feldspar, especially the plagioclase. The above statements are not intended to imply that no albite or soda has been introduced into any of the pegmatites after the original constituents. If such has taken place, however, the amount is exceedingly small compared with the amount of metamorphic albite and oligoclase. Cleavelandite is not characteristic

of the district, being known from one locality, the Wiseman property, No. 141, Group IV–A.

Origin of Texture f.

1. *Albite Veinlets in Perthite.*—Figures 12 and 13 illustrate a veinlet of albite and the perthite adjacent to it. Normally, the albite lamellæ are megascopically and microscopically quite regular. It will be noted that adjacent to the veinlet there is a relative deficiency of plagioclase lamellæ in the microcline. A similar condition is visible in a thin section of a specimen from No. 299, and is suggested megascopically in other cases. In such specimens, the coarse feldspars show deformation, and it is thought that the veinlets have resulted from recrystallization of albite squeezed from the nearby perthite lamellæ, and that the substance of the veinlets was part of the primary constituents of the pegmatite.

Figure 16 illustrates larger veinlets of plagioclase with muscovite, in perthite.

Figure 14 shows veinlets of albite cutting a single microcline individual, in which is also a reentrant angle containing albite. Mica flakes lie with the albite at two places in the perthite. On the other side of the specimen there are several irregular bodies of perthite in the albite (Fig. 15). The albite shows nearly parallel cleavage orientation at opposite sides of the specimen This condition, although the cleavage planes are slightly deformed, suggests large original grain size. In view of the relationship between perthite lamellæ and the albite veinlet shown in Figs. 12 and 13 and the deficiency of perthite lamellæ in the microcline of this specimen, these albite veinlets are regarded as being derived from perthite lamellæ. Although the irregular bodies of perthite on the other side seem residual after replacement, it is thought that they are more probably irregular projections from the larger individuals beneath, which may have been partly disrupted by the deformation shown elsewhere in the feldspars.

These small-scale phenomena are concluded to be metamorphic

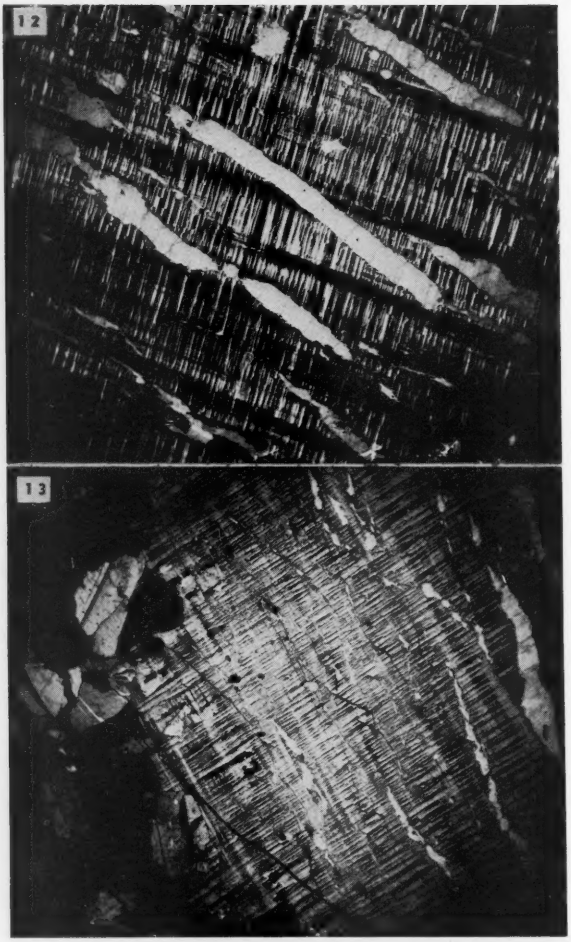


FIG. 12. Albite lamellæ in microcline (×9).
FIG. 13. Part of albite veinlet (left) and perthite (×9).

in origin; they are associated in places with the large-scale phenomena, also metamorphic, described below.

2. Broken Perthite.—In the first variant of Texture *f*, the perthite crystals and " corduroy " have been broken and the frag-

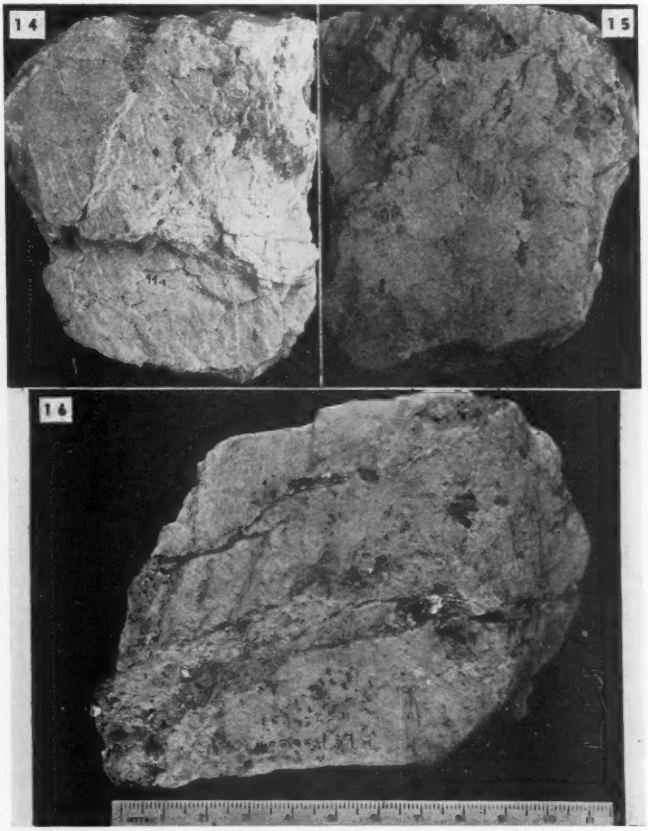


FIG. 14. Albite (white) and microcline (× 1/2), from No. 94.
FIG. 15. Reverse side of Fig. 14 (× 1/2).
FIG. 16. Albite veinlets with muscovite transecting perthite, from No. 462 (× 2/3).

ments are slightly separated by a much finer grained aggregate of oligoclase, quartz, and muscovite. The texture and composition of this relatively fine-grained aggregate or "matrix" vary considerably. The plagioclase individuals have been broken, and are so much deranged that their original grain size cannot be determined. The amount of admixed quartz ranges from 25 to 35 per cent. Muscovite is not always present. In some cases the corners of the perthite and of the perthite and "corduroy" have been rounded off (Fig. 17). This variant shows suggestive similarities to Texture *c*, previously described, and appears most certainly to have originated by deformation and recrystallization of primary oligoclase-perthite-quartz pegmatite. It is thought that plagioclase tended to break up into much smaller units than the perthite, due either to their smaller original size, or due to weakness of the plagioclase resulting from composition planes of albite and pericline twins, or possibly due to the force exerted by growing perthite crystals.

3. Rounded Perthite.—In the second variant of Texture *f* the large perthite and "corduroy" individuals are characteristically rounded and are enclosed in a "matrix" similar to that of the first variant. In some cases the plagioclase breaks with curved cleavage faces. Presumably the origins of these two variants are similar.

4. Jagged Perthite.—In the third variant of Texture *f* the perthite and "corduroy" individuals are subhedral or irregularly shaped (Figs. 18, 20, 21). In places, they interpenetrate with plagioclase that, judged by the near-continuity of its cleavage faces, must at one time have had a grain size of at least 12 inches. More commonly, the original grain size of the plagioclase has been reduced by ruptures and obscured by bending of the crystal structure that results in small curved cleavage faces. Quartz intergrowth is generally less plentiful in the perthite than in the plagioclase.

On account of the prevalence in the various types of pegmatites of magmatic plagioclase and the transitions from primary plagioclase to deformed plagioclase yielding small curved cleavage faces, it is thought that the latter originated by metamorphism

of magmatic plagioclase, and that the reentrant angles in the perthite and "corduroy" originated in the following ways: (1) Primary interpenetration of the perthite and plagioclase. (2) Squeezing of "matrix" into ruptures in perthite. (3) Chemical break-down of the microcline at points of stress, with the K_2O

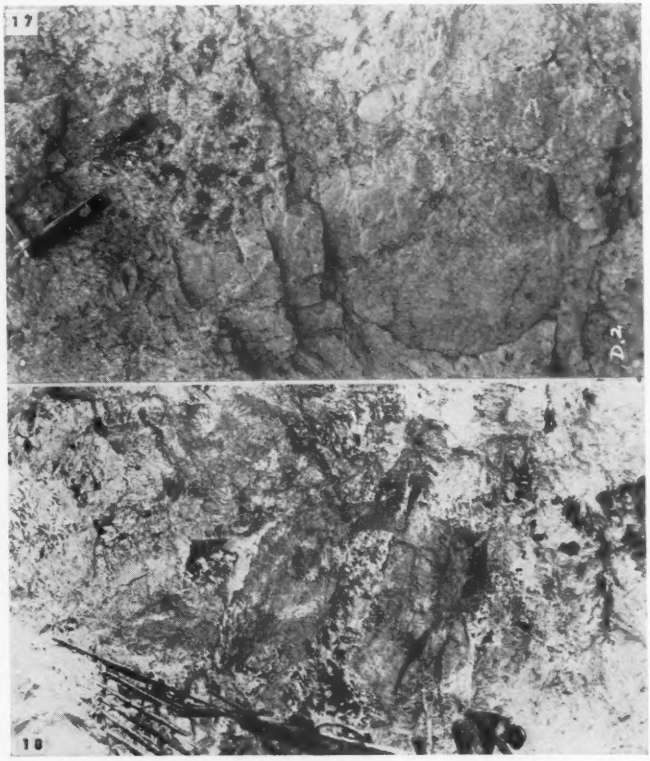


FIG. 17. Broken and rounded perthite. Fragments of one individual occupy half of the view (× 1/4).

FIG. 18. Working face of Pine Mountain Potash Feldspar Mine, No. 13. Plagioclase is white; perthite, gray; quartz, darker gray; muscovite, black.

going to form muscovite, and with albite encroaching on the perthite. Such a process might be called "replacement"; it would be metamorphic rather than metasomatic. According to Harker (15, p. 212), "There is abundant evidence that albite, in contrast

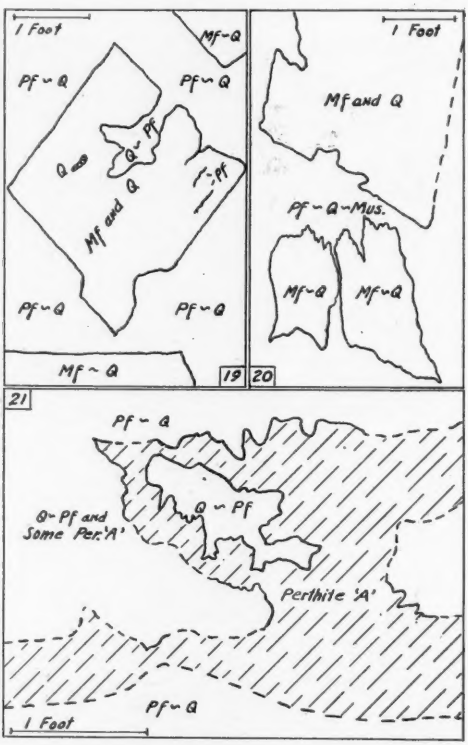


FIG. 19. Subhedral perthite with quartz (Mf and Q) in finer-grained aggregate of plagioclase and quartz (Pf and Q).

FIG. 20. Jagged perthite and quartz in fine-grained aggregate of plagioclase, quartz and muscovite.

FIG. 21. Boundary between perthite "A" (part of one crystal) and finer-grained aggregate in which quartz (Q) predominates over plagioclase (Pf).

with potash- and lime-feldspars, is stable under stress conditions . . . and must be ranked with the associated muscovite . . . among the most typical stress-minerals." (4) Replacement of the microcline in perthite by quartz without the removal of albite. Note the quartz and albite (grey and white) seeming to penetrate the perthite from the left, near the middle of Fig. 22. Here the ratio of albite to quartz is the same as the ratio of albite to microcline in perthite, *i.e.*, about 1 to 4, and so also in other cases, *e.g.*, at No. 94 (Fig. 19). One objection to this hypothesis is that generally in these pegmatites the quartz is thought to have replaced plagioclase more readily than microcline (See below). This hypothesis is distinctly more speculative than any of the other three above.

Although replacement of perthite by albite may have actually taken place to a small degree in the development of Texture *f*, it is one of the major conclusions of this study that a large-scale introduction of post-magmatic soda has not taken place in the Spruce Pine district.

Albite-Muscovite.

The muscovite associated with the features discussed above differs in texture and size from the normal muscovite of Stage 1 occurring in the least deformed shoots of oligoclase, perthite, and quartz. It is, therefore, thought to have formed in a different stage, presumably Stage 2-a. Muscovite, if present in the undeformed shoots, is commonly from 3 to 12 inches wide and occurs as isolated crystals (Fig. 8); whereas, at Nos. 13 and 58, for example, most of the muscovite is less than 2 inches wide, and is bunched together in a very irregular, scrappy aggregate (Figs. 18, 22). Figure 23 illustrates a somewhat similar occurrence of muscovite known only at the McKinney mine, No. 58. The middle of oligoclase crystals is crowded with small muscovite, and large muscovite wedges are scattered around the outer portion, radiating toward the center. Several of these oligoclase-muscovite masses in addition to perthite crystals of the same size are embedded in a large body of quartz. However, the perthite crystals contain relatively little muscovite.

On account of the size (up to 1 to 2 inches wide), the scrappy muscovite appears to have formed before complete expulsion of the volatile fraction of the pegmatite magma.

Whether the potash of the muscovite was derived from the break-down of the microcline, or existed in the residual liquid of

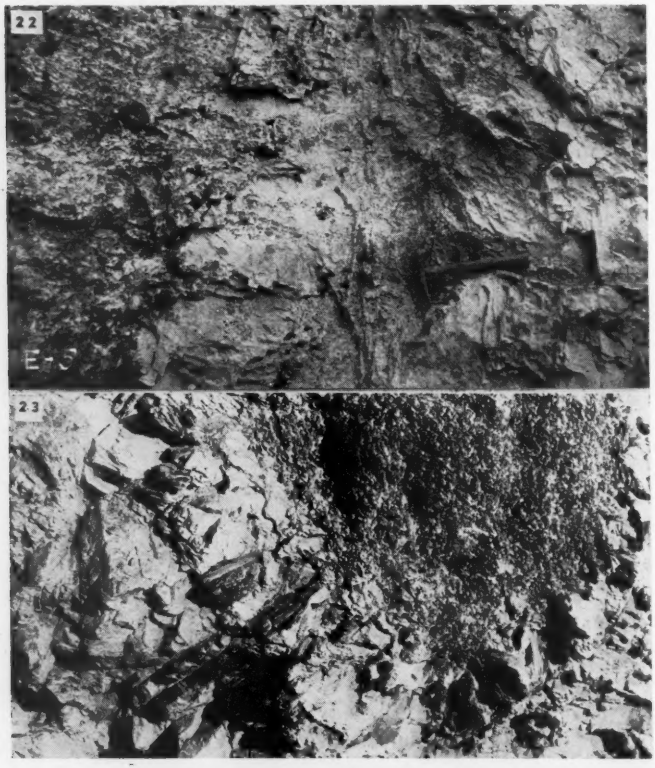


FIG. 22. Perthite of one individual (right and left of hammer) separated by albite-quartz aggregate. Note albite and quartz (white and dark gray) projecting into perthite at three places on left.

FIG. 23. Oligoclase crystal crowded with small muscovite books in center and with large books around margin (Length, 2 feet).

pegmatitic crystallization, is uncertain. Its common localization near the perthite points to the first hypothesis. De Lapparant (26) observed that greenish secondary sericite formed largely in the plagioclase of certain plagioclase-orthoclase porphyritic rocks, and concluded that the required potash was derived from orthoclase.

Albite-Quartz.

Some of the textures of the quartz-feldspar intergrowths suggest replacement of the perthite and plagioclase by quartz (Figs. 10, 24–27). The texture in the perthite might have resulted from the introduction of quartz along roughly parallel fractures, while the quartz intergrown with plagioclase is of a more irregular type, in keeping with the difference observed in the deformation of the two feldspars. In as much as there is no uniform relation between the amounts of the small muscovite and the excess quartz, it appears unlikely that the latter is to be attributed entirely to the break-down of microcline. On the evidence of the texture of the quartz intergrowth, observed differences in the rupturing of the feldspars, and the existence of quartz in the residuum of pegmatitic crystallization, it is concluded that the quartz of the intergrowths illustrated has replaced the feldspars. It is interesting to note that hypothetically such a process would remove soda in solution, for deposition elsewhere.

Zonal Distribution of the Pegmatites.

There is a strong suggestion of symmetry in the distribution of different compositional types of pegmatites in the district. This is hereafter referred to as "zonal distribution."

Most of the mica mines of Groups III–A and III–B, which contain but little potash feldspar, are distributed in a belt about six miles wide. This belt trends northeasterly and lies on the northwest side of the district. The belt extends from Celo Mountain in the southwest to Grassy Ridge in the northeast. The majority of the potash feldspar mines of Group IV, which carry variable amounts of sheet muscovite, are on the southeast side of the belt.

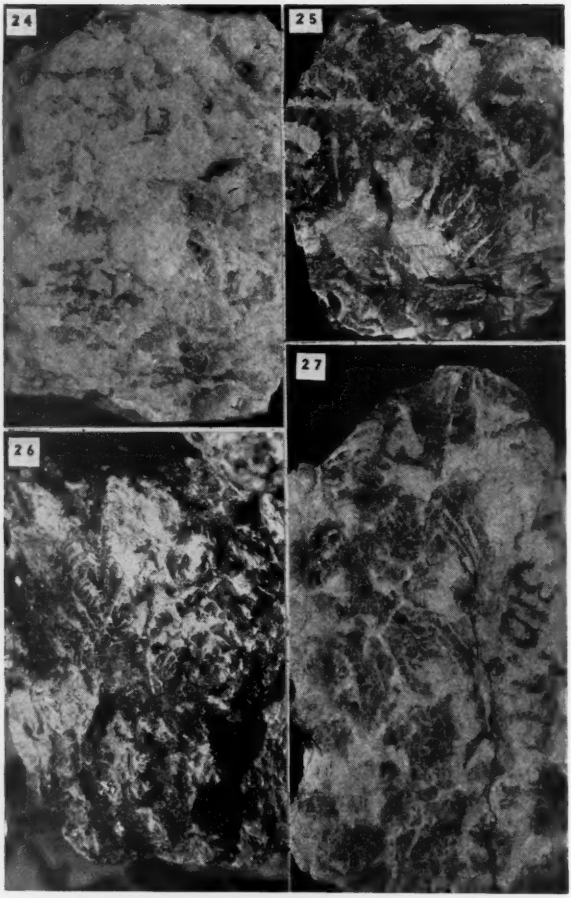


FIG. 24. Deformed oligoclase (An 11) with quartz intergrowth (×7/8).

FIG. 25. Plagioclase-quartz intergrowth (×7/8).

FIG. 26. Plagioclase-quartz intergrowth (×1/4); Pine Mountain mine.

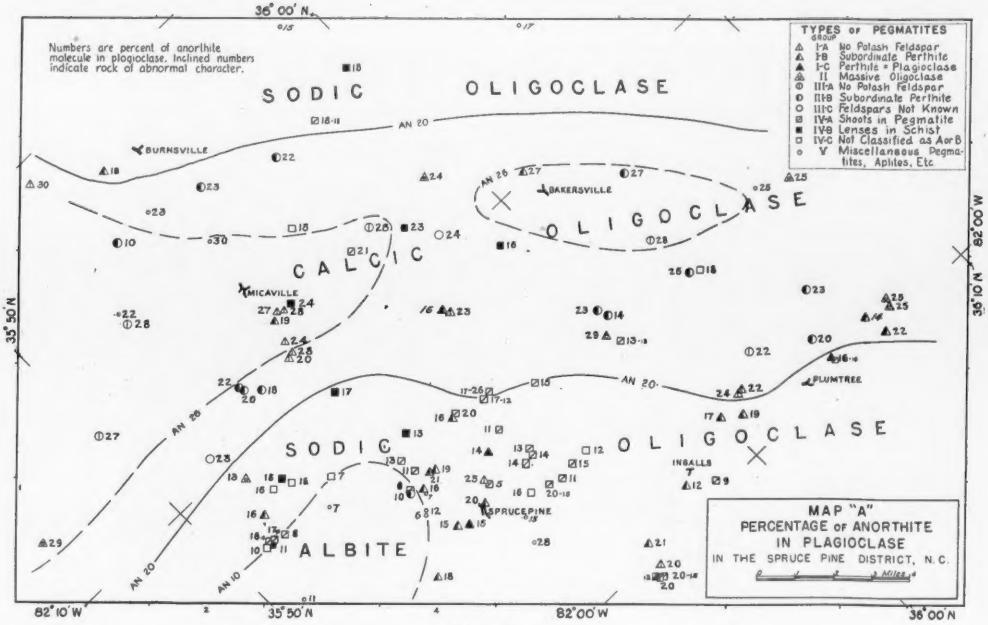
FIG. 27. Albite (An 10) and quartz intergrowth. Old Chalk Mountain mica mine (×7/8).

Moreover, the distribution of calcic oligoclase and of the more sodic plagioclase, shown on Map A, corresponds in general with the distribution of mica mines of Group III and potash feldspar mines of Group IV respectively. This is to be expected from the previously reached conclusion that perthite tends to be more abundant where the plagioclase is sodic. However, it should be born in mind that, in contrast to the normal condition, some of the best mica and potash feldspar mines contain respectively sodic oligoclase and calcic oligoclase. Therefore, the composition of the plagioclase by itself alone does not indicate the commercial limitations of any particular pegmatite.

The belt characterized by the presence of mica mines of Group III and calcic oligoclase (An 20 to An 30) is symmetrically bounded on either side by regions of sodic oligoclase (An 10 to An 20). The axis of symmetry of the belt is marked by two elongated areas in which the oligoclase is most calcic (An 27 to An 30). The distribution of the varying percentages of anorthite molecule in the plagioclase is in harmony with the tectonics of the region. The direction of the belt is parallel to: (1) the dominant strike of the pegmatites; (2) the dominant strike of the country rock; (3) the foliation of the latter; (4) the interfingering of the Carolina and Roan gneisses and (5) the trend of the main regional anticlinal uplift.

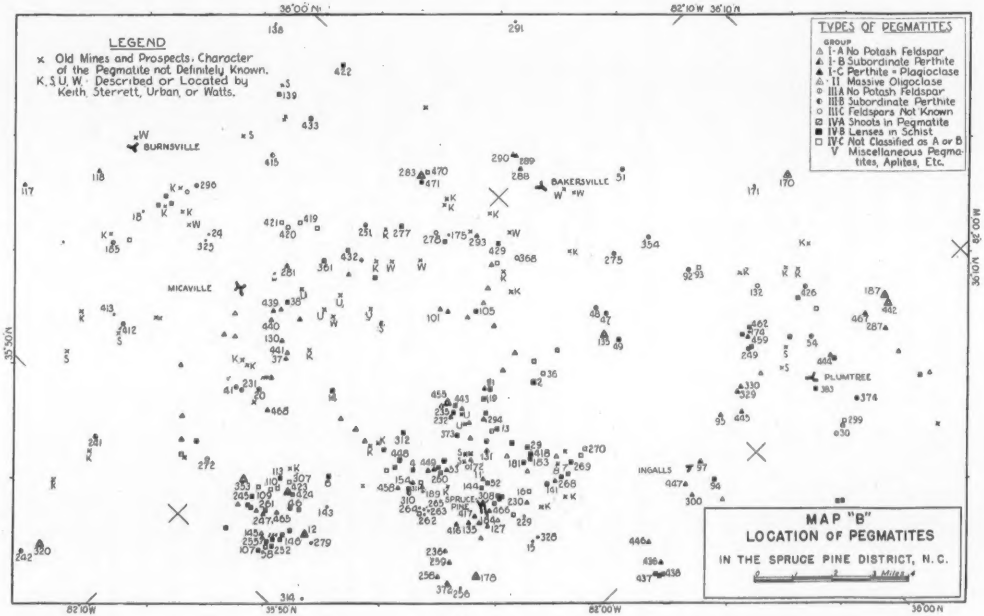
On the northwest side of the district, north of Burnsville, a few mica mines were formerly operated. The pegmatites are insufficiently known to classify into Groups III or IV, but the quantitative importance of these should not be over-estimated.

Exceptions to the above generalizations are of two types: (1) Some plagioclase is anomalous to the zone in which it occurs. (2) Some pegmatites of Groups III and IV occur out of their normal zone. The known exceptions cannot seriously impair the validity of the generalizations, but decrease the value of the generalization for prospectors. Although the present data indicate the "zonal distribution" described above, there are in the district many poorly exposed pegmatites and old abandoned mines that are imperfectly known. Further data tending to confirm or invalidate present data will therefore be of interest.


36° 00' N.
Numbers are percent of anorthite molecule in plagioclase. Inclined numbers indicate rock of abnormal character.
SODIC OLIGOCLASE
CALCIC OLIGOCLASE
SODIC OLIGOCLASE
ALBITE
AN 20
AN 25
AN 10
BURNSVILLE
BAKERSVILLE
MICAVILLE
PLUMTREE
INGALLS
SPRUCE PINE
TYPES OF PEGMATITES
GROUP
I-A No Potash Feldspar
I-B Subordinate Perthite
I-C Perthite + Plagioclase
II Massive Oligoclase
III-A No Potash Feldspar
III-B Subordinate Perthite
III-C Feldspars Not Known
IV-A Shoots in Pegmatite
IV-B Lenses in Schist
IV-C Not Classified as A or B
V Miscellaneous Pegmatites, Aplites, Etc
MAP "A"
PERCENTAGE OF ANORTHITE IN PLAGIOCLASE
IN THE SPRUCE PINE DISTRICT, N.C.
0 1 2 3 Miles 4
82° 10' W
35° 50' N
82° 00' W
36° 00' N
35° 50' N
82° 00' W

MAP A.

MAP A.


LEGEND
× Old Mines and Prospects. Character of the Pegmatite not Definitely Known.
K, S, U, W. Described or Located by Keith, Sterrett, Urban, or Watts.
TYPES OF PEGMATITES
GROUP
△ I-A No Potash Feldspar
▲ I-B Subordinate Perthite
▲ I-C Perthite + Plagioclase
△ II Massive Oligoclase
⊙ III-A No Potash Feldspar
◐ III-B Subordinate Perthite
○ III-C Feldspars Not Known
⊠ IV-A Shoots in Pegmatite
■ IV-B Lenses in Schist
□ IV-C Not Classified as A or B
V Miscellaneous Pegmatites, Aplites, Etc.
BURNSVILLE
BAKERSVILLE
MICAVILLE
PLUMTREE
INGALLS
SPRUCE PINE
MAP "B"
LOCATION OF PEGMATITES
IN THE SPRUCE PINE DISTRICT, N.C.
0 1 2 3 Miles
36°00' N.
82°10' W.
35°50' N.
82°00' W.

MAP B.

The explanation advocated for the "zonal distribution" of the pegmatites is the influence of hypothetical temperature zones or parallel belts, the hottest being in the middle, flanked by successively cooler ones. This hypothesis is suggested by the large number of zoned ore deposits related to igneous rocks. However, as such ore deposits are probably crystallized from passing solutions, in contrast to these pegmatites, the analogy cannot be strictly drawn. Fractional crystallization, influenced by loss of volatiles rather than by loss of heat, should be expected to yield different results in different temperature zones. This concept assumes that the pegmatites were all alike in composition in the liquid stage.

An alternative hypothesis assumes that there was a series of pegmatitic injections. The earlier of these were the more calcic and were injected in the middle zone. Later sub-magmas were progressively more potassic and were injected on the flanks of the middle zone, mainly on the southeast side. Although a progressive change in the composition of successive injections is a reasonable expectancy, no convincing explanations for the bilateral symmetry of the zonal distribution can be given. Therefore the first hypothesis is preferred.

Elucidation of the genetic relations of the various types of pegmatites is complicated by evidence of stress, which must have squeezed off the unconsolidated portions of many pegmatites and affected mineral composition as well as texture.

Summary of Conclusions.

The common pegmatites of the district contain more plagioclase than potash feldspar. The plagioclase of these, and of the deposits yielding mica and feldspar, crystallized during the "magmatic" stage. A common texture suggesting replacement of potash feldspar by plagioclase was produced largely by metamorphism of the magmatic constituents, during a late magmatic stage. Minor amounts of albite are doubtlessly formed by replacement. Muscovite and quartz replace plagioclase more than they replace microcline.

Types of commercial sheet muscovite deposits (Groups III–A

and III–B) that have yielded a large proportion of the total output of North America contain calcic oligoclase predominating heavily over potash feldspar. Most of these deposits and the common pegmatites of similar composition are localized in a central, northeast-southwest belt. Most of the commercially important potash feldspar deposits of the district, which have yielded a large proportion of the output of North America since 1914, contain about equal amounts of sodic oligoclase and perthite. These deposits and common pegmatites containing sodic oligoclase are found mainly in a zone along the southeast side of the calcic oligoclase zone, and again in a symmetrical position on the northwest side.

It is suggested that a symmetrical distribution of temperature zones was responsible for the present zonal distribution of the different kinds of pegmatite.

GENESIS OF PLAGIOCLASE AND COMMERCIAL SHEET MUSCOVITE IN PEGMATITES.

Much of the recent literature on pegmatites has emphasized hydrothermal replacement in types of pegmatite that may be referred to somewhat ambiguously as "granite pegmatite." Attention is called to some structures indicating replacement of potash feldspar that are due not to metasomatic processes of soda-bearing solutions, but to other types of replacement; to different implications of the term "granite pegmatite"; and to certain debatable generalizations regarding the composition and genesis of pegmatites yielding feldspar and sheet muscovite.

Magmatic Plagioclase.—The crystallization of normal pegmatitic plagioclase (magmatic), in the same stage as potash feldspar, is too well established to need discussion. References to examples have recently been furnished in the classifications of Johannsen (18) and Landes (24). The crystallization sequence of the common minerals has generally been considered similar to that in plutonic rocks. In specific cases it appears that the plagioclase began forming before potash feldspar (2, pp. 22 and 27; 28). Although pegmatites containing magmatic plagioclase in more than accessory proportions are not as common as "com-

mon granite pegmatite," the bulk of plagioclase in pegmatites is probably of this origin.

Hydrothermal Plagioclase.—There has been general acceptance of the concepts expressed by Hess (10, 11), Landes (23, 24, 25), and Schaller (33, 34) especially as to the introduction of rare minerals and sodic albite by metasomatic processes or hydrothermal solutions. However, in the literature there is no general accord regarding specifically what minerals are solely of replacement or hydrothermal origin. Although, in most cases, the metasomatic introduction of soda and rare elements has been studied in common granite pegmatites lacking magmatic plagioclase, Landes refers to a number of complex pegmatites containing magmatic plagioclase (24, pp. 97–105) as well as hydrothermal albite.

The small proportion of all pegmatites that are affected by later replacements is brought out by Landes (24, p. 96). Wright (47) has minimized the amount of metasomatic replacement in the pegmatites discussed by Derry (6).

Pegau states that microcline in the Amelia area is replaced by soda feldspar; the context implies hydrothermal metasomatic replacement by oligoclase as well as albite, but no evidence is cited (29). Doubtlessly the cleavelandite is hydrothermal, but convincing evidence of a similar origin for oligoclase would be of great interest.

Late Magmatic Plagioclase.—Two authors recently reached the conclusion that plagioclase, albite and oligoclase, crystallized after microcline, and that the microcline was resorbed or replaced.

The "albite pegmatites" described by Stockwell (40) commonly contain microcline, the amount of which may exceed albite. The grain size is from 1 to 5 inches. Some of the microcline crystals are rounded or embayed and cut by stringers, or are "residuals" with common crystal orientation. The matrix of these includes albite in a variety of textures. Cleavelandite is present, and partly penetrates the microcline. Stockwell concludes that the matrix crystallized partly from interstitial magma, which reacted with the microcline and did not form by replacement of solid rock, except to a very limited degree. Watson, in

an unpublished dissertation (44), gives some descriptions of structure that are similar to those of Stockwell. For most of the pegmatites Watson believes that microcline crystallized first and was partly resorbed, or replaced by plagioclase ranging in composition from andesine to pure albite; and that there was continuous and progressive freezing with conditions varying from those of typical magma to hydrothermal (45; 44, p. 15).

The structures described in the above papers appear rather similar to some found in the Spruce Pine district.

"Replacement" by Metamorphic Plagioclase.—In the Spruce Pine district practically all the plagioclase crystallized originally before or contemporaneously with the potash feldspar, and both feldspars date from the same stage; however, some of the plagioclase has suffered re-crystallization and microcline may have been metamorphically replaced at the same time. Normally, the plagioclase is at least equal in amount to the potash feldspar and may greatly exceed the latter.

In some of the common pegmatites and in others classed as potash feldspar producers, deformation has resulted in the development of secondary structures described under the caption Texture *f* and discussed above under Replacement in Stage 2-a. During this stage, which was probably late magmatic, plagioclase was bent and mashed, and potash feldspar was rounded and embayed or "replaced" to a limited extent by plagioclase. Reentrants in perthite are fairly common, but the greater number of the reentrants are concluded to be due to primary interpenetration, or to squeezing of the mashed plagioclase into fractures in the more competent perthite. With minor exceptions, whatever "replacement" of potash feldspar by plagioclase took place was a metamorphic effect rather than due to the introduction of soda by metasomatic processes.

In some cases the relations between the feldspars referred to above resemble superficially the criteria of replacement presented by Schaller (34, p. 63) and there are marked similarities to the pegmatites of Maryland and to descriptions of the southeastern Manitoba albite pegmatites (see above). In as much as the magmatic crystallization of oligoclase and calcic albite in advance

of potash feldspar in pegmatites has generally been recognized, it appears possible that effects suggesting the late origin of such feldspars and the resorption or replacement of microcline in other areas may have been produced by the process advocated here for the Spruce Pine district.

Granite Pegmatite.—Before proceeding with the next section it may be worthwhile to note some ambiguities in the use of the term "pegmatite."

The feldspars of "granite pegmatite," where that term is used in restricted senses, are mainly potash feldspars (27, pp. 752, 756), or may be restricted to the alkalic varieties, with plagioclase occurring only as an accessory or intergrowth if it is present at all (18, pp. 73, 116). To indicate the principal varieties of granite pegmatites, Johannsen uses as adjectives "kali-alaskite" and "alaskite" for common granite pegmatites (pegmatites *sensu stricto*) containing no plagioclase more calcic than "sodaclase," or $Ab_{95}An_5$, and "leucogranite" for those with more calcic plagioclase. Kali-alaskite differs from alaskite only in that less than 5 per cent sodaclase is present. Landes (24, p. 97) uses "alaskite pegmatite" for pegmatites containing potash feldspar and quartz alone; his definition of the character of the feldspar is therefore the same as in Johannsen's kali-alaskite pegmatite.

According to Johannsen (18, p. 73), the term "pegmatite" as commonly used connotes specifically "granite pegmatite," the most common kind, and unless modified excludes the more basic pegmatites such as granodiorite pegmatites. Thus, there is no comprehensive term to embrace all kinds of pegmatites. Moreover, different writers may use the term "granite pegmatite" in various restricted meanings pointed out above, rather than in the broadest sense.

In reading Schaller's generalization about "pegmatites" it must be born in mind that he probably used the term in the strict sense, *i.e.*, for the kali-alaskite or alaskite pegmatites of Johannsen, containing only the sodaclase variety of plagioclase (33, p. 279).

Hess (11, p. 450), in defining the composition of granite peg-

matite dikes, states that they "are made up of quartz, potash feldspars, and in most cases muscovite . . ."; it appears that he excludes the leucogranite pegmatites, and others more basic, from consideration in his classification and discussion.

Commercial Mica and Feldspar.—Commercial feldspar and sheet muscovite have been obtained in important quantities from leucogranite and leucotonalite pegmatites as well as from alaskite pegmatites; and the replacement hypotheses of Schaller and Hess, which appear to have been applied by them mainly to alaskite pegmatites, cannot be extended to feldspar and muscovite deposits in general.

Spence, although he says that pegmatites yielding feldspar are similar to ordinary granite in composition, believes that the processes described by Schaller and Hess have been active in their formation, and that the original constituents were largely silica, alumina, and potash (36, pp. 1–2). In a later passage (p. 8) he implies that the proportions of potash and soda feldspars (*i.e.*, the presence of plagioclase) depend on the degree of alteration of the original potash feldspar, and that the commercial muscovite evolved solely by replacement of potash feldspar. In an earlier paper, Spence states that commercial muscovite is derived exclusively from granite pegmatites (35). None of these generalizations are applicable to the Spruce Pine district.

Lindgren implies that potash and soda feldspars and sheet muscovite are obtained in important quantities only from granitic pegmatites (27, p. 758). The definition of the feldspar content of Lindgren's "granite pegmatite" is not clear. He states that they "consist mainly of coarsely crystallized orthoclase and quartz with muscovite; . . ." (27, p. 752). However, six pages later, the presence of albite, and further on, oligoclase, is noted; the first passage seems to imply that the albite and oligoclase are merely accessory. Lindgren applies Schaller's hypothesis to mica and feldspar deposits in general—extension shown by the Spruce Pine pegmatites to be unwarrented.

Horton's hypothesis regarding the origin of mica-yielding pegmatites, "These solutions first deposited the granitoid minerals —potash feldspar and quartz" (13), and his later implications

that commercial sheet mica is formed only by replacement of potash feldspar do not appear applicable to the Spruce Pine district. Horton's generalization on the replacement origin of commercial sheet muscovite is similar to the conclusion of Anderson (3) regarding the mica deposits in Idaho. Although much of the commercial muscovite of the Spruce Pine district is of secondary origin, the author's data indicate that the above generalizations as to the replacement origin of all commercial sheet mica and the composition of the pegmatites require revision.

Although some of the commercial sheet mica of the Spruce Pine pegmatites formed in secondary structures with quartz, either as fissure fillings or as replacements, an important part is primary. Replacement, by solutions introducing potash from a distant part of the same pegmatite, is doubtlessly an important factor; its quantitative importance cannot be stated. However, the replacements are in plagioclase and wall rock, and not in potash feldspar. The proportions of primary and secondary mica cannot be estimated. Primary sheet mica occurs in pegmatites ranging in composition from predominantly calcic oligoclase and quartz with little or no potash feldspar, to calcic albite with perthite and quartz, all in about equal proportions. Secondary structures occur to some extent in the albite pegmatites, but are better known in the calcic oligoclase pegmatites. Potash appears to have a slight tendency to crystallize more as feldspar in albite pegmatites and more as muscovite in calcic oligoclase pegmatites (see Zonal Distribution of the Pegmatites).

Speaking of pegmatites yielding mica, Sterrett (39, p. 6) says: "in many places, however, a variety of plagioclase, either albite or oligoclase, makes up a part or all of the feldspar." The best yielding mica mines of New Hampshire visited by the author are all in pegmatite having plagioclase as the dominant feldspar. The question is raised whether this type of mica-bearing pegmatite may not prove to be important in other areas besides the Spruce Pine district.

In the Spruce Pine district, some of the lime-soda spar (oligoclase) is obtained from pegmatites containing little or no potash feldspar. The potash spar normally occurs in leucogranite peg-

matites having plagioclase about equal in amount to perthite; in some cases the proportion of plagioclase may be even higher. The primary origin of the plagioclase, which may be as calcic as $Ab_{70}An_{30}$, has already been discussed. The leucogranite variety is included by Bastin's definition (4) of commercially important pegmatites. The minerals of the latter are said to be "the same as those most abundant in ordinary granites"; farther on he states: "the feldspar deposits . . . differ notably with respect to the proportions in which the most abundant minerals are present. . . ." These words may reasonably be construed to imply the occurrence in some deposits of large proportions of oligoclase. Galpin (8) has noted potential sources of feldspar in which the proportion of soda is equal to that of potash, and in range of composition the quartz-bearing pegmatites of Southern Norway appear from description to be similar to those of the Spruce Pine district (2, pp. 18–23).

Bastin's description of the composition of pegmatites yielding feldspar embraces the deposits of the Spruce Pine district better than does the description of Lindgren, quoted above. Nevertheless, a revision so as to include the leucotonalite pegmatites yielding oligoclase is needed.

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June 14, 1939.

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DISCUSSION AND COMMUNICATIONS

TEMPERATURE AND DEPTH IN HYPOGENE ORE DEPOSITION.

Sir: As Buddington, and Butler in commenting on Buddington's paper, point out,[1] difficulties and inconsistencies arise in classifying hypogene deposits as though temperature and depth varied concomitantly. Butler writes:

> "It seems best to keep depth classification independent of temperature classification or to combine them in a compound term."

Many others, including the writer, doubtless have reached the same conclusion. The question is far from being merely of academic interest for unless it is recognized that deposits of the same or analogous mineralogy may be formed at different depths, or that deposits of widely differing mineralogy may be formed at the same depth, faulty or erroneous conclusions or surmises will be reached regarding depth possibilities for ore in a mine or district, and regarding the vertical range of hypogene ore deposition.

It is not difficult to see that depth below the surface during ore formation is not necessarily a measure of the temperature existing during ore deposition. Brief comment will suffice to emphasize this. Deposition of diagnostic minerals at widely varying depths, horizontal zoning in which lower temperature minerals are at the same depth as higher temperature minerals and superimposition of high and low temperature minerals at the same depth in the same body, prove the point. Relatively hot centers of present-day volcanism and relatively cold conditions at a horizontal distance from these centers, have analogy with a similar horizontal tem-

[1] Buddington, A. F.: High temperature mineral associations at moderate to shallow depths. ECON. GEOL., 30: 205–222, 1935. Butler, B. S.: ECON. GEOL., 31: 115–118, 1936.

perature zoning around magmatic intrusives. The considerable difference in the vertical temperature gradient in different parts of the earth's crust indicate important temperature variations at the same depth as considerable or great depths are attained (for instance 3 to 4 miles). The emplacement of intrusives at variable depths, followed by ore deposition before the intrusives have cooled entirely, doubtless is responsible for wide variations in depth-temperature relations during ore deposition. Structural conditions and rock character; variable time relations between magmatic differentiation and ore deposition; the character of the differentiating magma from which the hypogene fluids are derived; the character of the fluids themselves; the variable depth-source of the ore-bearing fluids; variable heat of the intruded country rock and a number of other factors, conceivably or certainly produce variable depth-temperature relations. This must be true of the same general locus as well as of different regions.

In view of all this, one reads of attempts at a vertical building up of various hydrothermal zones, one on top of another, with doubt and perplexity. Graton's stimulating paper [2] is a striking modern example of this. By assuming vertical extensions of certain deposits and combining the extended deposits in vertical "intensity zones" (which apparently are dominated by temperature) great vertical range is indicated for the hypothermal deposits and for the hydrothermal family as a whole. But it is obvious that since the "intensity zones" may be horizontally disposed as well as vertically superimposed they may be unreliable indicators of depth. The Morro Velho deposit is set on top of the Kolar deposit and the Porcupine veins are set on top of both, as though it could be assumed safely that the variable "intensities" of the lodes of these districts showed precisely the relative depths at which they were formed. This seems an unjustifiable assumption.

Graton's proposed leptothermal zone "takes something off the top of Lindgren's mesothermal and off the bottom of Lindgren's epithermal." But its characteristics are revealed in "Sales outermost zone at Butte" so evidently it may lie alongside of the meso-

[2] Graton, L. C.: The hydrothermal depth-zones, Lindgren Volume, A. I. M. E., 1933.

thermal zone as well as above this zone. "Telethermal" deposits are deposited above epithermal deposits, even though epithermal deposits may be deposited at or just below the surface. And deposits that conform mineralogically to the telethermal class, at Leadville, are relatively deep-seated.[3] These comments do not argue against the possible need and usefulness of the terms proposed by Graton, but they emphasize the inconsistency and confusion that arises, and is bound to arise, from attempts to classify hypogene ore in depth zones and at the same time to use mineralogy (and from it a deducible temperature or "intensity" of formation) to characterize the zones. Great depth and high temperature and shallow depth and low temperature doubtless are commonly co-existent, and an increase of temperature with depth, which may be quite uniform, must be prevalent. To the extent that these conditions exist, a mutually dependent temperature-depth classification may be satisfactory. But in view of the proof or indication of variable temperatures during ore deposition, at the same depth in the same region and in different regions; and the indication of the same temperature during ore formation at variable depths, in the same or different regions, it is plain that confusion and uncertainty will arise unless depth and temperature be considered as possible independent variables. The difficulty, perhaps, is most serious in grouping deposits from different parts of the world.

Depth is so important to the scientist and to the miner alike that its retention in classification and in the minds of investigators is highly desirable. Butler's suggestion to combine depth and temperature in a compound term seems excellent. At least until more is known of the genesis of hypogene ore, temperature appears to be the most fundamental criterion. In spite of imperfections and unwarranted conclusions in special cases, mineralogy is a guide to temperature. It should become increasingly valid and useful with advancing knowledge. Depth should be judged from structure, geologic history, geologic environment and other factors, including mineralogy and indications of pressure. Visualization of the surface during ore deposition is the ultimate ob-

[3] Loughlin, G. F., and Behre, C. H. Jr., Lindgren Volume, pp. 41–42, 1933.

jective. Though it is difficult or impossible in most cases to make satisfactory close estimates of depth of ore formation, broad estimates are possible in many cases. Where they are not, the depth part of the hyphenated classification may be left blank.

Unfortunately, the "thermal" classification terms now in use, or proposed, appear to embrace both temperature and depth in the same word. Nevertheless, it may not be difficult to agree that telethermal, epithermal, leptothermal, mesothermal and hypothermal be expressions that signify variable temperatures of formation, telethermal being the coolest and hypothermal the hottest. If not, new words to express variable temperature *only* may be used. Shallow, intermediate and deep may be added after a hyphen where it is desired or possible to express depth; or left off where uncertain or unknown, or where depth and temperature are consistent and there seems no need to stress the depth. This might apply, for instance, where a telethermal deposit is both low temperature and shallow and a hypothermal deposit both high temperature and deep.

E. Y. Dougherty.

Toronto, Ontario,
Jan. 3, 1940.

REVIEWS *

A Descriptive Petrography of the Igneous Rocks. Vol. I. Introduction, Textures, Classifications, Glossary. Rev. edit. By ALBERT JOHANNSEN. Pp. 318, Figs. 145. Univ. of Chicago Press, 1939. Price, $4.50.

During the eight years that have elapsed since the appearance of the first edition, this valuable text has become too well known to need detailed description here. The increase in the number of pages is entirely accounted for by the addition of an extremely valuable 51 page "glossary of all the rocks described in the other volumes." In this limitation lies the only weakness. Although 780 rock names are here defined, this glossary, like the others in the book, will not provide an unfailing source of information for the reader who wants a dictionary of petrographic names.

The typographical and other small errors of the first edition have all been corrected; the quantitative classifications of Lacroix and Tröger have been substituted for that of Hodge; two pages of comment, headed by a fine illustration of a monkey-wrench (p. 159) on Niggli's modification of Johannsen's classification, and Andreatta's modification of Niggli's modification, have been added. The preface to this new edition is likewise concerned mainly with a defense of the author's classification and nomenclature. Lastly, a better picture of Werner has been substituted. These are the only changes, and the rest of the book most accurately can be described as a re-impression of the same high order of publishing excellence. With these new and valuable additions the already high popularity of this textbook will not only continue, but will be enhanced.

DAVID GALLAGHER.

The Geology of South Africa. By A. L. DUTOIT. 2nd. edit. Pp. 546; figs. 68; pls. 41; geol. map. Oliver and Boyd, London, 1939. Price, 28/

This book ranks as one of the finest regional geologies and the geological world owes a debt to Dr. DuToit for his painstaking, careful work. The

* Books noted under *Reviews* and *Books Received* may be ordered through the Economic Geology Bookshop, W. S. Bayley, Urbana, Ill., but orders for official reports and single copies of Journals should be sent directly to their publishers.

second edition surpasses its well known predecessor. It has been largely rewritten and many revisions are noticeable. The older material has been brought up to date. The regions covered have been pushed northward from South Africa to the Zambesi River, thus including all new information regarding the geology and mineral resources of the lower third of the African continent including Southern Rhodesia, S. W. Africa, Portugese East Africa and Bechuanaland. The colored geological map has also been revised. There is new information about the tillites and the older geological formations, particularly the Witwatersrand system. One cannot escape surprise, however, in the explanation advanced on page 89 to account for the presence of the pyrite, gold and carbon in the Banket. The geological problems of South Africa have always proved fascinating and this able presentation by Dr. TuToit further whets interest in this geological paradise.

ALAN BATEMAN.

Principles of Sedimentation. By W. H. TWENHOFEL. 1st. edit. Pp. 610; Figs. 44. McGraw-Hill Book Co., New York, 1939. Price, $6.00.

This is not a revision of the author's "Treatise on Sedimentation" although, as might be expected, it does incorporate much of the material of that volume. Here, emphasis is placed on the concept that sediments are the products of heritage and environment that also affect transportation, deposition and subsequent modification of sediments. The environment is first presented, then the resulting products.

The following chapter headings give an idea of the content and also indicate the similarity to the "Treatise:" Environmental Factors; Classification and Consideration of Environments; Origin of Inorganic Sediments; Interrelations of Organisms and Sediments; Transportation and Deposition; Classification of Sediments and Sedimentary Rocks; Clastic Sediments; Chemical Sediments—carbonate, silicious, ferruginous, manganese, carbonaceous, evaporates and miscellaneous; Structural Features of Sedimentary Origin; Textures and Colors of Sediments.

The subjects indicated above are thoroughly covered, but illustrations are few. References at the end of each subsection, fairly well up-to-date, are helpful. Perhaps too many substances and deposits are included under sediments. It is a bit surprising, for example, to find oxidized and supergene sulphides of zinc, lead and copper so listed. The volume contains a wealth of material regarding sedimentation but it is difficult to find any that is not included in the "Treatise on Sedimentation," although the order is somewhat different. The price seems rather prohibitive.

Conservation in the United States. By members of the faculty of Cornell University (A. F. Gustafson, H. Ries, C. H. Guise, W. J. Hamilton, Jr.). Pp. 445; Figs. 232. Comstock Pub. Co., Ithaca, N. Y., 1939. Price, $3.00.

There are four parts to this volume: I, Soil and Water Resources; II, Forests, parks and grazing lands; III, Wildlife; IV, Mineral resources (H. Ries). Each part covers the subject matter broadly and is illustrated by some excellent photographs, particularly those of soil erosion. Under mineral resources, the use of scrap metals is emphasized. The various minerals are considered briefly under occurrence, properties, source, mining, reserves, competition and methods of conservation; 24 pages are devoted to metals and 43 to non-metals. The book should find use for elementary purposes.

BOOKS RECEIVED.

DAVID GALLAGHER.

Summary of Records of Surface Waters of Texas, 1898–1937. C. E. ELLSWORTH. Pp. 154. U. S. Geol. Surv., W. S. P. 850. Washington, 1939. Price 20¢. *Mainly tabulated statistics.*

Coal Resources of McCone County, Montana. A. J. COLLIER AND M. M. KNECHTEL. Pp. 80; pls. 15; figs. 49; 1 geologic map in color. U. S. Geol. Surv., Bull. 905. Washington, 1939. Price 75¢.

Subsurface Geology and Oil and Gas Resources of Osage County, Oklahoma. N. W. BASS, L. E. KENNEDY, J. N. CONLEY, AND J. H. HENGST. Pp. 46; 1 map. U. S. Geol. Surv., Bull 900–C. Washington, 1939. Price 40¢. *Part 3, Townships 24 and 25 North, Ranges 8 and 9 East.*

The Mining Laws of Canada. A. BUISSON. Pp. 110. Canada Bureau of Mines, No. 795. Ottawa, 1939. Price 25 cts. *A digest of Dominion and Provincial laws affecting mining.*

The Canadian Mineral Industry in 1938. Pp. 102. Canada Bureau of Mines, No. 804. Ottawa, 1939. Price 25 cts. *Reviews by the Staff of the Bureau of Mines.*

Investigations in Ore Dressing and Metallurgy. Pp. 147; figs. 3; 1 pl. Canada Bureau of Mines, No. 792. Ottawa, 1939. Price, 50 cts.

Geology of the South Onaman Area. W. W. MOORHOUSE. Pp. 30; figs. 7; maps and plans 6; 1 map in color, 24″ × 12″, scale 1:63,360. Ontario Dept. Mines, 47th Annual Report, part 8. Toronto, 1939. *Pre-Cambrian geology and gold prospects.*

Geology of the Schreiber Area. G. A. HARCOURT (SW part) AND M. W. BARTLEY (NE part). Pp. 45; figs. 18; maps 5; 1 map in color, 40″ × 24″, scale 1:31,680. Ontario Dept. Mines, 47th Annual Report, part 9. Toronto, 1939. *Pre-Cambrian geology and gold deposits; some exceptionally fine photographs.*

Bibliography of the Geology and Mineral Resources of Arizona. E. D. WILSON. Pp. 164; 1 fig. Ariz. Bur. Mines, Geol. Ser. 13, Bull. 146. Tucson, 1939.

Oil and Gas Seeps in Smith County, Kansas. K. L. LANDES AND J. M. JEWETT. Pp. 8; 1 fig. Kansas Geol. Surv., Mineral Resources Circ. 12. Lawrence, 1939.

Western Kansas Oil and Gas Developments During 1938. W. A. VER WIEBE. Pp. 104; figs. Kansas Geol. Surv., Mineral Resources Circ. 13. Lawrence, 1939. *Arranged by counties; abundant data; very informative.*

Secondary Recovery of Petroleum. Part I—Bibliography. J. I. MOORE. Pp. 99. Kansas Geol. Surv. Bull. 25. Lawrence, 1938. *A very comprehensive bibliography. Under each of the following headings the papers are arranged alphabetically by authors, core analysis, flow of fluids, water flooding, solution flooding, adhesion tension, water treatment, repressuring, and mining. The author has personally read and abstracted here nearly all the papers listed.*

Relation of Thickness of Mississippian Limestone in Central and Eastern Kansas to Oil and Gas Deposits. W. LEE. Pp. 40; pls. 3; figs. 4; tables 3; map 24″ × 36″ of Kansas showing iso-thickness lines for Mississippian and other data. Kansas Geol. Surv. Bull. 26. Lawrence, 1939.

A Study of the Equilibrium Method of Determining Moisture in Coal for Classification by Rank. O. W. REES, F. H. REED, AND G. W. LAND. Pp. 30; figs. 14. Illinois Geol. Surv., Rep't of Invest.—No. 58. Urbana, 1939. *Conclude method is not satisfactory.*

Preliminary Geological Maps of the Pre-Pennsylvanian Formations in Part of Southwestern Illinois. S. WELLER AND J. M. WELLER. Pp. 11; figs. 2; maps 3. Scale 1:62,500. Illinois Geol. Surv., Rep't of Invest.—No. 59. Urbana, 1939. *Three line-maps on tracing paper, suitable for printing and coloring, covering Waterloo, Kimmswick, New Athens, Crystal City, Renault, Baldwin, Chester, and Campbell Hill Quadrangles.*

Preliminary Geologic Map of the Mississippian Formations in the Dongola, Vienna, and Brownfield Quadrangles. S. WELLER AND J. M. WELLER. Pp. 7; 1 fig.; 1 map. Illinois Geol. Surv., Rep't of Invest.—No. 60. Urbana, 1939. *Same type map as above.*

Greenbrier County, West Virginia. P. H. PRICE AND E. T. HECK. Pp. 870; pls. 53; figs. 23. With map atlas containing one geologic map in color, 58″ × 38″, scale 1:62,500, and one topographic map, same scale. West Virginia Geol. Surv., Morgantown, 1939. *A detailed and comprehensive monograph on the geology and resources of the State's second largest county.*

Limestones of West Virginia. J. B. MCCUE, J. B. LUCKE, AND H. P. WOODWARD. Pp. 574; pls. 38; figs. 15; one sample and outcrop map in color, 34″ × 32″, scale 1:500,000, of the whole State. West Virginia Geol. Surv., Vol. XII. Morgantown, 1939. *Detailed information on the location, quantity, and quality of one of the State's most important and valuable natural resources, together with geological, statistical, technological, and economic data.*

SCIENTIFIC NOTES AND NEWS

ROLAND D. PARKS, authority on mining economics, has been appointed assistant professor in geology at the Massachusetts Institute of Technology. He will leave the Michigan College of Mining and Technology next fall and will give special courses in mine evaluation, mineral economics, and elements of mining. His appointment is in conjunction with a new course of study that is designed to meet the modern demands of mining engineering and the mineral industries by providing sound training in economics as well as the fundamentals of science. Broad opportunity for individual specialization will also be given students under this curriculum.

ROLAND BLANCHARD, chief geologist of Mt. Isa Mines, Ltd., Queensland, Australia, was awarded the Gold Medal of the Chemical, Metallurgical and Mining Society of Africa last October.

I. B. CROSBY has been studying a hydroelectric project for the Costa Rica Light and Traction Co.

GEORGE D. OSBORNE of Sydney University, on sabbatical leave for petrological study at Cambridge and Harvard Universities, has just completed a tour of Canada and the United States under the auspices of the Carnegie Corporation, prior to his return to Australia.

O. H. LEONARDOS, formerly with the Brazil Bureau of Mines, is professor of geology at the University of Brazil in Rio de Janeiro.

PHILIP M. LEBARON, recently with the U. S. Geological Survey, has accepted a position at Mascot, Tenn., on the geological staff of the American Zinc Co.

Recent speakers before the department of Geology and Geography at Northwestern University have included M. KING HUBBERT on "Theories for the Flow of Ground Water;" A. R. DENISON of the Amarada Petroleum Corp. on "The Geologist in the Petroleum Industry" and GEORGE D. OSBORNE on "Geologic Research in New South Wales."

JOHN W. FINCH has resigned as director of the U. S. Bureau of Mines.

H. W. STRALEY, III, of the department of geology of Baylor University, Waco, Texas, spoke before the Houston Geological Society Jan. 17 on "The Problems of the Geology of the Atlantic Coastal Plain." He also recently conducted a group of advanced students to study the geology of the Arbuckle Mts., near Ardmore, Okla.

OSCAR H. HERSHEY, nationally known Oakland, Calif. geologist, died on December 11, 1939.

GEORGE W. TOWER, JR., geologist and mining authority attached to the Denver office of the U. S. Securities and Exchange Commission, died September 13, 1939.

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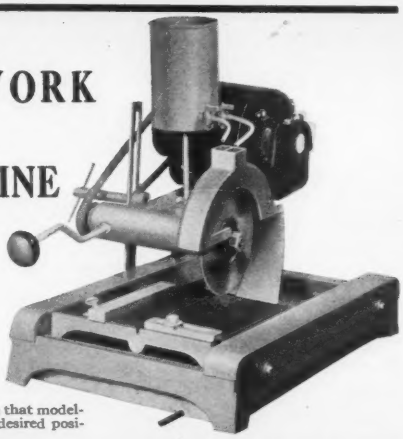

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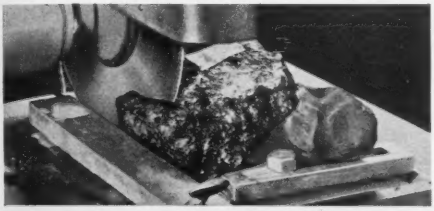

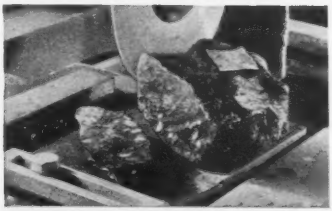

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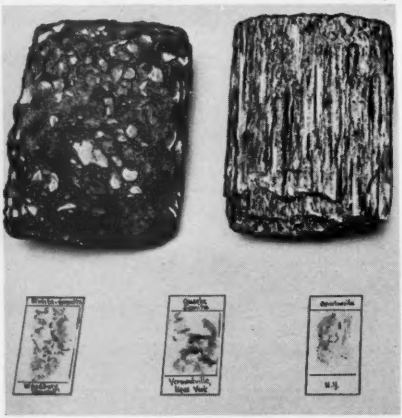

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